THE

ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

VOLUME LXXVI

JULY–DECEMBER 1932

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS

THE CAMBRIDGE UNIVERSITY PRESS, LONDON
THE MARUZEN COMPANY, LIMITED, TOKYO
THE COMMERCIAL PRESS, LIMITED, SHANGHAI

PUBLISHED JULY, SEPTEMBER, OCTOBER,
NOVEMBER, DECEMBER, 1932

COMPOSED AND PRINTED BY THE UNIVERSITY OF CHICAGO
PRESS, CHICAGO, ILLINOIS, U.S.A.

Astronomical Obs
Wshr

CONTENTS

NUMBER I

NUMBER II

NUMBER III

NUMBER IV

NUMBER V

VOLUME LXXVI NUMBER 1

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

JULY 1932

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

July 1932 Vol. LXXVI, No. 1

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

The Astrophysical Journal is published by the University of Chicago at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois, during each month except February and August. ¶ The subscription price is $6.00 a year; the price of single copies is 75 cents. Orders for service of less than a half-year will be charged at the single-copy rate. ¶ Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, Canary Islands, El Salvador, Argentina, Bolivia, Brazil, Colombia, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru, Hayti, Uruguay, Paraguay, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Balearic Islands, Spain, and Venezuela. ¶ Postage is charged extra as follows: for Canada and Newfoundland, 30 cents on annual subscriptions (total $6.30); on single copies, 3 cents (total 78 cents); for all other countries in the Postal Union, 80 cents on annual subscriptions (total $6.80), on single copies, 8 cents (total 83 cents). ¶ Patrons are requested to make all remittances payable to The University of Chicago Press, in postal or express money orders or bank drafts.

The following are authorized agents:

For the British Empire, except North America, India, and Australasia: The Cambridge University Press, Fetter Lane, London, E.C. 4. Prices of yearly subscriptions and of single copies may be had on application.

For Japan: The Maruzen Company, Ltd., Tokyo.

For China: The Commercial Press, Ltd., Paoshan Road, Shanghai. Yearly subscriptions, $6.00; single copies, 75 cents, or their equivalents in Chinese money. Postage extra, on yearly subscriptions 80 cents, on single copies 8 cents.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when losses have been sustained in transit, and when the reserve stock will permit.

Business correspondence should be addressed to The University of Chicago Press, Chicago, Illinois.

Communications for the editors and manuscripts should be addressed to: Otto Struve, Editor of THE ASTROPHYSICAL JOURNAL, Yerkes Observatory, Williams Bay, Wisconsin.

The cable address is "Observatory, Williamsbay, Wisconsin."

The articles in this journal are indexed in the *International Index to Periodicals*, New York, N.Y.

Applications for permission to quote from this journal should be addressed to The University of Chicago Press, and will be freely granted.

Entered as second-class matter, January 17, 1895, at the Post-Office at Chicago, Ill., under the act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 15, 1918.

PRINTED IN THE U.S.A.

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXXVI JULY 1932 NUMBER 1

A PHOTO-ELECTRIC STUDY OF ϵ AURIGAE

By C. M. HUFFER

ABSTRACT

The brightness of the variable star ϵ Aurigae, which has a period of 27 years, *was measured* with the *photo-electric photometer* at the Washburn Observatory on *98 nights* between January, 1928, and May, 1931.

There was observed the *expected loss of light*, similar to an eclipse, *beginning in April, 1928*, and *ending in May, 1930*. In addition, *irregular short-period fluctuations* amounting to as much as 0.2 mag. were found. These fluctuations were detected at the beginning of the observations and they continued during the minimum and to the end of this series. It was hoped that a period could be found to represent the maxima or minima of these secondary variations. A submultiple of 336 days seemed most likely, but was found to be unsatisfactory. The average interval between maxima or minima is roughly of the order of 100 days. The depths of the minima are also unequal and irregular, as well as non-periodic. A correlation with synchronous variations in the spectrum has yet to be established.

During what has been called the constant phase of minimum there was also observed a steady decrease of brightness amounting to about $0^{M}06$. The mean brightness at maximum light was found to be approximately the same before and after the minimum.

The three comparison stars were found to be constant in light. The probable error of a magnitude of ϵ determined on one night is $\pm 0^{M}006$, which is far less than the irregularities of the star's light.

The following *elements were adopted* for the primary minimum: $t_1 = \text{J.D. } 2425725 + 9883^{d} \cdot E$; loss of light $= 0^{M}81$; total duration $= 754$ days.

The recent minimum of ϵ Aurigae is the fourth since its discovery by K. Fritsch in 1821. According to P. Guthnick,[1] Fritsch announced the discovery on February 20, 1821, in a letter to J. E. Bode. This letter seems to have been forgotten, for in 1843 J. F. J. Schmidt remarked that the star was apparently variable, but made no reference to Fritsch. The variability was definitely established during the minimum of 1847–1848, when it was observed by Schmidt, F. W. A. Argelander, and E. Heis. The decrease of light was not sufficiently observed to determine the middle of the eclipse,

[1] *Geschichte und Literatur*, p. 130.

only one observation (by Schmidt) falling on the downward curve. Schmidt continued observations until his death, securing in all nearly five thousand estimates between 1843 and 1884, including the minima of 1847–1848 and 1874–1875. These have been discussed and published by H. Ludendorff,[1] who had earlier discussed other available material.[2] In this paper he published the light-elements and classified the star as an Algol variable with a period of 9905 days.

For the minimum expected to begin in the summer of 1928, photo-electric observations were begun at the Washburn Observatory on January 20, 1928, and were continued nearly as often as the weather would permit, except for about two months each year when

TABLE I

H.R.	Star	R.A. 1900	Decl. 1900	Harvard Visual Magnitude	Photo-electric Magnitude	Spectrum
1605	ϵ Aurigae	$4^h54^m.8$	$+43°40'$	3.4–4.1	3.42–4.23	F5p
1599	5 Aurigae	4 54.4	39 15	6.00	6.23	F5
1668	B.D.+46°970	5 03.3	46 50	5.59	5.96	F5
1729	λ Aurigae	5 12.1	+40 1	4.85	5.13	G0

the altitude of the star was too low during the hours of darkness. The star was measured by Mr. Stebbins on 30 nights and by Mr. Huffer on 68 nights.

The variable was compared with the other stars listed in Table I. Following our usual plan of using neutral-shade glasses, on any night two shades were used on ϵ, the first to reduce ϵ to approximate equality with 5 Aurigae and H.R. 1668 = B.D. +46°970, the second to approximate equality with λ Aurigae. Then as ϵ varied progressively in brightness in the course of weeks, the shades were changed as shown in Table II.

The absorption of each shade was determined by measures of ϵ without a shade and through a given shade; also by intercomparisons of the shades with each other.

Allowance for differential atmospheric extinctions was made in accordance with our usual practice,[3] with use of a revised schedule for the factor f. Because of the favorable location of the comparison stars, the algebraic sum of the corrections for extinction was usually

[1] *Astronomische Nachrichten*, **192**, 389, 1912. [2] *Ibid.*, **164**, 81, 1903.

[3] *Publications of the Washburn Observatory*, **15**, 16, 1928.

less than $0^{\mathrm{M}}.01$ on each date, even when the altitude was very low during April and May. This relationship did not hold at low eastern altitudes. For this reason H.R. 1668 was used as the only comparison star during July and part of August. At no time was the outstanding correction for extinction more than $0^{\mathrm{M}}.04$.

TABLE II

J.D. 242	With 1668 and 5	With λ
5266–5373	$2^{\mathrm{M}}.71$	$1^{\mathrm{M}}.81$
5443–5566	2.26	1.30
5566–5940	1.81	0.69
5945–6047	2.26	1.30
6054–6466	2.71	1.81

Sky	Scale	f
Fine	$4\frac{1}{2}$	1.5
Good	4	1.7
Fair	$3\frac{1}{2}$	2.1
Poor	3	2.6

The resulting photo-electric magnitudes of ϵ Aurigae are given in Table III, second column. Each magnitude is usually the mean resulting from the comparison of ϵ with the three comparison stars. The magnitudes of the comparison stars were found by adding the respective photo-electric color-indices to the Harvard visual magnitudes; then the values were adjusted from the measures on many nights. The zero of the system depends on the Harvard visual magnitudes of the three comparison stars.

In the last three columns of Table III are given the residuals from the mean magnitude of ϵ for each night. From these residuals were derived the probable errors as follows: from 5 Aurigae, $\pm 0^{\mathrm{M}}.008$; from H.R. 1668, $\pm 0^{\mathrm{M}}.007$; from λ Aurigae, $\pm 0^{\mathrm{M}}.010$; for mean, $\pm 0^{\mathrm{M}}.006$. There is no evidence of variability among the comparison stars, and the measures fix the light of ϵ at any time well within the irregular fluctuations of the star itself.

The magnitudes of ϵ Aurigae are plotted in Figure 1*a*, the time scale being in Julian days.

After observations on four nights from January 22 to March 4,

TABLE III

Observations of ε Aurigae

J.D. 242+	Mean Magnitude	Residuals 5	Residuals 1668	Residuals λ	J.D. 242	Mean Magnitude	Residuals 5	Residuals 1668	Residuals λ
5266.554	3.37	$+0^{\mathrm{M}}.01$	$0^{\mathrm{M}}.00$	$-0^{\mathrm{M}}.01$	5888.753	4.30	−0.01	+0.02	−0.01
5268.561	3.37	.00	+ .01	− .01	5889.794	4.30	.00	− .01	+ .01
5278.672	3.43	.00	− .02	+ .02	5898.742	4.30	− .01	.00	+ .01
5297.656	3.46	+ .02	+ .01	− .02	5902.767	4.30	+ .01	− .01	.00
5310.683	3.49	+ .01	.00	− .01	5909.769	4.29	− .01	.00	+ .01
5320.588	3.53	+ .01	− .01	.00	5917.708	4.21	.00	.00	.00
5336.599	3.45	+ .02	− .01	− .01	5921.720	4.16	− .02	− .01	+ .03
5346.604	3.39	+ .03	.00	− .03	5924.683	4.14	− .02	− .01	+ .03
5349.584	3.39	+ .01	+ .02	− .03	5930.676	4.09	− .02	+ .01	.00
5356.586	3.34	+ .02	.00	− .02	5940.663	4.06	.00	− .04	+ .04
5365.601	3.34	− .01	− .01	+ .02	5945.622	4.03	+ .03	− .01	− .02
5373.610	3.34	.00	− .01	+ .01	5948.699	4.01	+ .01	.00	− .01
5443.863	3.77	......	......	......	5951.643	4.02	.00	− .01	.00
5450.858	3.80	......	......	......	5967.597	3.95	.00	− .01	+ .01
5468.817	3.84	......	......	......	5975.757	3.89	− .01	+ .03	− .02
5496.828	3.95	.00	.00	− .01	5994.716	3.79	.00	+ .01	− .01
5511.835	4.07	.00	.00	.00	5998.723	3.79	.00	+ .02	− .03
5517.763	4.11	.00	.00	.00	6005.692	3.75	.00	+ .01	− .01
5525.745	4.14	.00	+ .01	− .01	6015.672	3.65	− .02	− .01	+ .02
5542.717	4.21	.00	+ .01	− .01	6038.604	3.56	.00	+ .02	− .02
5549.790	4.21	+ .01	.00	− .01	6044.585	3.59	+ .04	− .01	− .03
5554.713	4.24	.00	− .01	+ .01	6047.640	3.54	+ .01	.00	− .01
5566.667	4.24	.00	+ .01	− .01	6054.593	3.51	+ .01	+ .01	− .01
5573.650	4.20	+ .01	− .01	.00	6063.643	3.51	.00	+ .01	− .01
5585.587	4.20	− .01	− .02	+ .03	6070.589	3.48	+ .02	.00	− .02
5588.847	4.17	− .03	.00	+ .02	6080.581	3.47	− .01	+ .01	.00
5589.831	4.16	− .01	.00	+ .01	6088.592	3.39	+ .04	− .01	− .02
5599.592	4.16	− .01	+ .01	......	6090.590	3.38	.00	+ .01	.00
5601.584	4.17	.00	− .01	+ .01	6099.601	3.41	+ .01	− .01	.00
5610.560	4.21	.00	.00	.00	6199.862	3.53	+ .01	− .01	......
5615.740	4.22	+ .01	.00	.00	6209.846	3.49	− .01	+ .01	− .01
5623.572	4.23	+ .01	− .01	.00	6222.804	3.42	+ .02	.00	− .01
5637.545	4.25	.00	.00	+ .01	6236.782	3.39	+ .01	.00	− .01
5643.660	4.25	− .01	− .01	+ .01	6241.818	3.41	.00	.00	.00
5652.628	4.25	+ .01	+ .01	− .02	6246.785	3.42	.00	.00	− .01
5662.704	4.24	.00	− .01	+ .01	6262.773	3.47	.00	.00	.00
5675.612	4.25	+ .01	.00	− .01	6268.739	3.44	+ .01	− .01	.00
5685.616	4.22	− .02	+ .01	+ .01	6280.702	3.39	− .01	.00	.00
5698.579	4.20	.00	+ .01	− .01	6287.692	3.42	+ .02	− .02	− .01
5715.587	4.19	.00	+ .01	− .01	6301.695	3.46	+ .01	.00	.00
5723.603	4.18	+ .01	− .02	.00	6308.642	3.46	+ .01	.00	− .01
5738.583	4.26	− .01	+ .04	− .03	6321.651	3.48	+ .01	.00	− .01
5802.869	4.27	......	......	......	6338.601	3.46	.00	+ .01	− .01
5811.847	4.22	......	......	......	6351.756	3.50	− .01	− .01	+ .02
5823.824	4.23	......	......	......	6358.708	3.42	+ .01	+ .01	− .02
5827.798	4.26	......	......	......	6376.695	3.39	.00	+ .01	− .02
5841.794	4.27	......	......	......	6410.639	3.42	+ .01	− .01	.00
5865.797	4.22	.00	.00	.00	6435.581	3.40	− .02	+ .02	.00
5869.787	4.22	−0.03	+0.01	+0.02	6466.602	3.43	−0.04	+0.01	+0.03

NOTES ON TABLE III

J.D. 2425266	Shades 2.26 on ϵ and 0.69 on λ
5268	Shades 2.71 and 1.81 on ϵ, one set
5373	Low altitude, poor
5443–5468	Because of low altitude 1668 only was used as comparison star
5588	One set
5599	One set with 5 and 1668
5738	Low altitude, large dark current, poor
5802–5841	Same as 5443
5869	One set only with 5
5948	One set only with 5
6015	Extra shade 0.85 on all stars by mistake
6044	Smoke
6088	One set only with 5 and 1668
6199	One set with 5, three sets with 1668
6287	Bright moon, smoke
6351	Poor
6466	Sky poor, low altitude

1928, with steady decrease in brightness at the rate expected at the beginning of eclipse, we announced in *Harvard Announcement Card* **61** that the eclipse had probably begun. However, this loss of light was rapidly recovered, and what we had observed was not the beginning of the eclipse, but one of the secondary fluctuations which have continued to the present time. It has not been possible to find a period for these oscillations, nor so far as we know has any correlation between them and observed changes of radial velocity been detected.

Figure 1*b* shows the variations in light due to these secondary oscillations. While the absence of a second spectrum shows that the system of ϵ Aurigae is almost certainly not the common one of two spheres, mutually eclipsing, a mean light-curve computed on the assumption of an eclipsing system makes a convenient basis for testing the secondary oscillations. At maximum, the normal magnitude was adopted as $3^{M}_{.}42$; and at minimum, $4^{M}_{.}23$; total loss due to assumed eclipse, $0^{M}_{.}81$. In Figure 1*b* the residuals are plotted as differences between the observed magnitudes and these adopted values, except on the downward and upward curves.

To obtain the residuals during the phases between maximum and minimum, a light-curve by H. N. Russell's method was computed, on the basis of uniform disks, the ratio of radii $k=0.315$, and with loss of light $0^{M}_{.}81$. This curve roughly satisfied the observations and

was sufficient to show that the non-periodic fluctuations were present at all times. The greatest secondary variation from the adopted mean curve occurred just before the beginning of the de-

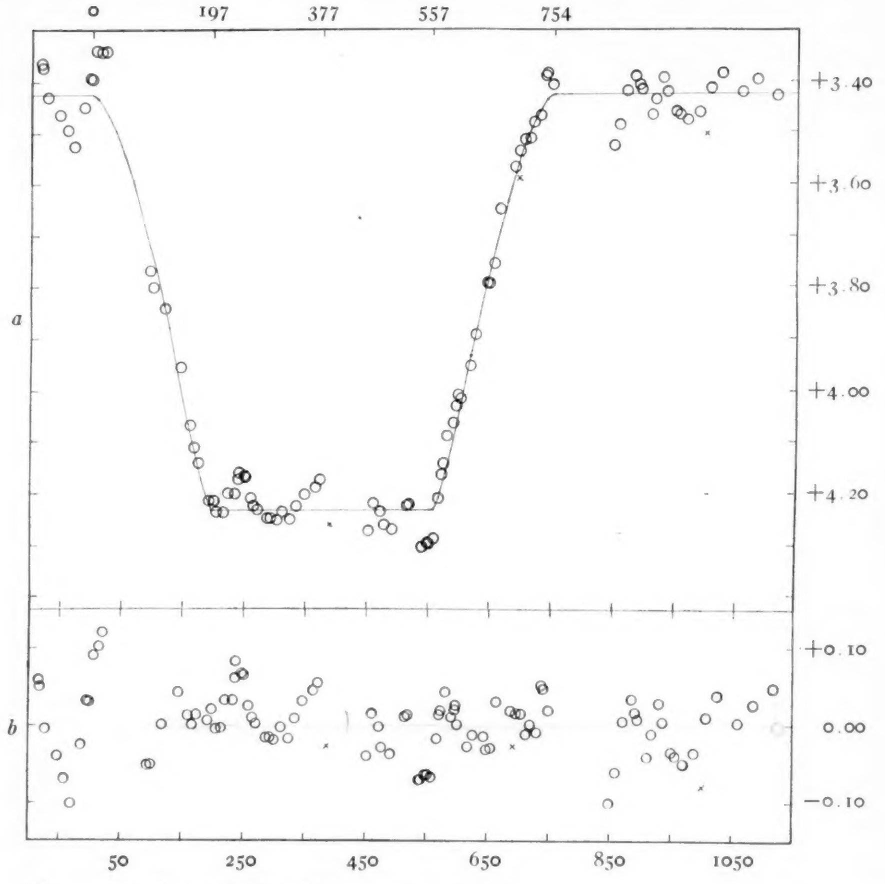


FIG. 1.—*a*) Photo-electric light-curve of 7 ϵ Aurigae
Abscissa: phase in days
Ordinate: magnitudes.
b) Secondary fluctuations of ϵ Aurigae
Deviations (magnitudes) of observed points from smooth curve plotted against phase in days (abscissa).

crease to minimum. The observed amplitude at that time was $0^{\mathrm{M}}.185$; but since the decrease had begun before the time of the last observation, the total variation shows as $0^{\mathrm{M}}.22$ on Figure 1*b*. The smallest fluctuations occurred during the increase of light and amounted to $0^{\mathrm{M}}.075$.

An inspection of Figure *1b* shows indications of evenly spaced minima at four dates: 5316, 5650, 5982, and 6324. The average interval between these dates is 336 days. However, some scattered observations at the next computed date, 6660, show an undoubted maximum rather than a minimum. Likewise periods of one-half, one-third, or other fractions of 336 days seem to be ruled out, and it has been quite impossible to find any regularity in these fluctuations, which often seem to go through a cycle in something more than 100 days. These variations are too large to be due to errors of observation or defects of the instrument and must be caused by changes of brightness of the star.

During minimum there was also a steady decrease of brightness which was neglected in drawing the mean curve. This decrease is small, about $0^{\mathrm{M}}.06$, but must be considered real. The mean maximum brightness after minimum is approximately the same as before minimum.

Ludendorff determined the period on the basis of the beginning and ending of the "eclipse" and on the ending of "totality." Since our observations show these points to be masked by the secondary fluctuations, it appeared better to use all points on the descending and ascending branches of the curve, and determine the middle date. Ludendorff has published corresponding dates for the two preceding minima. Using these three dates and adjusting the resulting elements, we find

$$t_1 = \text{J.D. } 2425725 + 9883^{\mathrm{d}} \cdot E = 1929.308 + 27^{\mathrm{y}}.059 \cdot E\,.$$

The observed and computed dates for the middle of the three minima, and the resulting residuals, are as tabulated.

Observed	Computed	O−C
J.D. 2405960	2405959	$+1^{\mathrm{d}}$
2415840	2415842	−2
2425726	2425725	+1

For the recent minimum, loss of light is $0^{\mathrm{M}}.81$; duration of decrease, 197 days; duration of minimum, 360 days; duration of increase, 197 days; and entire eclipse, 754 days.

The minimum of 1928–1929 occurred 19 days earlier than predicted from Ludendorff's period of 9905 days and the observed minimum of 1901–1902.

The low density that must exist in this system is well known. As seen from a distant star, Saturn with a period of 29.5 years would transit across the sun in about 1.7 days, while the corresponding time for ϵ Aurigae, with a slightly shorter total period, is at least 197 days. If we consider the star eclipsed at minimum simply to be a sphere, then no matter whether the companion is a single body or a swarm of meteorites, the upper limit of density of the main body is found to be 5.6×10^{-7}, computed from the formula,

$$\rho<\frac{\sin^3 S}{P^2 \sin^3 \frac{\pi d}{P}},$$

where ρ is the density on the solar standard, S the apparent semi-diameter of the sun, $16'$, P the period in years, and d the duration of the decrease or increase in light. Similarly, on the doubtful basis of two spheres the mean density of the system comes out 2.1×10^{-8} irrespective of the distribution of mass.

A secondary minimum in 1947 may be roughly predicted from Ludendorff's spectroscopic elements,[1] which are $P=27.1$ years; $T=1920.6$; $e=0.35$; $\omega=319\overset{\circ}{.}7$. The loss of light due to such an eclipse should amount to about $0\overset{\mathrm{M}}{.}06$, and would be difficult to detect, since it is smaller than the irregular fluctuations which may be expected to continue. The middle of the next primary minimum should occur on May 14, 1956.

The star ϵ Aurigae has long been outstanding in the list of Algol variables because of its long period and resulting low density. Several spectroscopists have suspected short-period variations in radial velocity, and it may be possible in the future to correlate these with the short-period fluctuations in brightness. However, it is probable that this variable will long remain a puzzle as well as an anomaly.

I am indebted to Professor Joel Stebbins for his share in the observations, and for advice in the preparation of this paper.

Washburn Observatory
Madison, Wis.
April 11, 1932

[1] *Sitzungsberichte* (Berlin), **9**, 49, 1924.

CHARACTERISTIC FEATURES OF SOLAR PROMINENCES[1]

By EDISON PETTIT

ABSTRACT

Spectra of prominences.—An objective-grating spectrogram taken at the eclipse of June 8, 1918, by Anderson and Babcock shows the prominences without the overlapping flash spectrum. The results of measures on this spectrogram are given in a table of wave-lengths and intensities. These data show that, with two exceptions, all the lines in the flash spectrum brighter than 30 on S. A. Mitchell's scale are found in prominences; 14 lines fainter than intensity 30 are also found, all of temperature classes III–V. "Metallic" prominences show all the lines in Mitchell's table brighter than 15, except those of ionized barium. Save in brilliancy there is probably no real difference between the spectra of common and metallic prominences.

Forms of prominences.—Prominences may be divided into five classes: (1) active, (2) eruptive, (3) spot, (4) tornado, and (5) quiescent, each of which is illustrated. An examination of prominences of classes 1, 2, and 5 in projection on the disk, combined with their appearance at the limb, shows them to be in form like sheets of flame standing on edge. The larger prominences are connected with the chromosphere only at intervals along the lower edge through columns like the roots of a tree.

Dimensions.—The thickness of prominences varies from 6000 to 12,000 km. The length as projected on the disk is seldom less than 60,000 km or greater than 600,000 km. A height of 50,000 km is quite common, and eruptive prominences have been known to reach a height of two-thirds of a solar diameter. The volume of a prominence is often of the order one hundred times that of the earth.

Masses of prominences.—After suitable correction of the observational material, the work of Pannekoek and Doorn shows that an ordinary prominence has a hydrogen content of 2×10^{13} atoms per cubic centimeter. The calcium content is negligible. On this basis a representative prominence 10,000 km thick, 200,000 km long, and 50,000 km high would have the mass of a cube of water 15 km on an edge. The mass of the largest prominence on record, that of May 29, 1919, would be about four times as much.

Distribution of the elements.—Comparison of both $H\alpha$ spectroheliograms and drawings made at the spectrohelioscope in $H\alpha$ with spectroheliograms in K_2 shows that the forms of prominences in these two lines are essentially the same. An examination of the eclipse spectrum extends this conclusion to other lines. The absence of certain streamers and faint clouds from the $H\alpha$ observations may be due to instrumental conditions. There is, however, some reason to suppose that the effect may be real, since an electrical field would produce just this result. Disturbances in the corona about prominences are perhaps evidence that the Ca^+ atoms attract the electron streams in the corona.

Motions in eruptive prominences.—The principle of uniform motion modified by sudden increases in velocity already found was tested (1) by a review of the best examples already given, (2) by an examination of new material published by other observers, (3) by new material obtained for the purpose, and (4) by examining the impartiality of the measurements. The conclusion is that this principle of motion in eruptive prominences is real.

Light-pressure.—If light-pressure is operative in producing the motion, the Doppler effect which separates the absorption lines of the prominence from the corresponding absorption lines of the photosphere should also produce a separation of the hydrogen and calcium atoms. No separation of this kind was observed, however, in the eruptive prominence of August 6, 1931.

Expansion of eruptive prominences and the coronal density-gradient.—It is shown that the density of the prominence of August 6, 1931, followed the law $d \approx R^{-6}$, and also that

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 451.

the density of the corona follows the same law. The expansion of the prominence therefore keeps its density in step with that of the corona.

Tornado prominences.—These small objects are of the order 5600–22,000 km in diameter and 25,000–97,000 km in height. A case is reported in which the angular velocity became so high that the vortex exploded. No lateral motion over the solar surface has been observed.

Quiescent prominences.—Detailed measures of condensations appearing in a quiescent prominence revealed a continuous internal turbulence with velocities ranging up to 15 km/sec.

Height of the chromosphere in $H\alpha$.—The height of the chromosphere was measured with the spectroheliscope on several days of good definition and found to be 5500 km. This value is a little less than that found visually with the spectroscope.

Previous papers[1] describe an attempt made at the Yerkes Observatory to determine the characteristics of the forms and motions of the prominences. The present paper, which may be considered an extension of these early studies, is based on data obtained in part at Mount Wilson and in part at the Yerkes Observatory. The equipment available for this work has been the Rumford spectroheliograph attached to the 40-inch telescope at Yerkes, made available through the kind invitation of Professor E. B. Frost, the 13-foot spectroheliograph and spectrographs at Mount Wilson, and the spectrohelioscope recently invented by Dr. G. E. Hale.

SPECTRA OF PROMINENCES

There are, in general, two spectral classes of prominences corresponding to (1) the prominences most commonly seen, and (2) the "metallic" prominences, usually brilliant spikes, often found in sunspots. The spectra of common prominences as seen without an eclipse consist of the Balmer series of hydrogen, the H and K lines of calcium, and the helium line D_3. The helium lines λ 6562 and λ 7065 appear faintly, and the Ca^+ triplet $\lambda\lambda$ 8498, 8542, and 8662 can be photographed.[2] It is possible that the hydrogen line λ 10049 (H_6 of the Paschen series), observed by H. D. Babcock[3] in the spectrum of the photosphere, occurs in prominences, but thus far it has not been found.

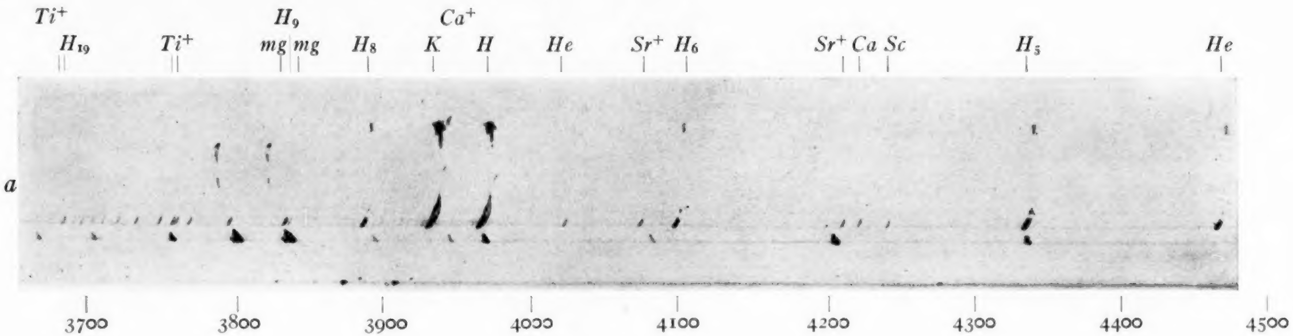
[1] Pettit, *Astrophysical Journal*, **50**, 206, 1919; *Publications of the Yerkes Observatory*, **3**, Part IV, 1925.

[2] K. Burns, *Lick Observatory Bulletin*, **10**, 67, 1920; see also L. d'Azambuja, *Annales de l'Observatoire de Paris, Section d'Astrophysique à Meudon*, **8**, Fasc. II, p. 100, 1930.

[3] Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths, *Carnegie Institution of Washington Publication*, No. 396; *Papers of the Mount Wilson Observatory*, **3**, 223, 1928.

PLATE I

a



b

No. 31

a) Objective-grating spectrum (part only, original dimensions) of prominences, eclipse of June 8, 1918, by Anderson and Babcock.

b) Eruptive prominence (No. 31) of June 18, 1929. G.C.T. of exposures: (*a*) 16^h56^m; (*b*) 17^h35^m; (*c*) 17^h54^m; (*d*) 18^h50^m; (*e*) 19^h32^m; (*f*) 19^h50^m; (*g*) 20^h10^m; (*h*) 20^h23^m; (*i*) 20^h32^m; (*j*) 20^h46^m; (*k*) 20^h56^m; (*l*) 21^h04^m.

The spectra of prominences may be studied most conveniently at a solar eclipse. An objective-grating spectrogram taken between second and third contacts shows the spectrum as a series of images of the prominences corresponding to the various lines. Such a photograph was made by J. A. Anderson and Babcock[1] at the eclipse of June 8, 1918, in the first-order spectrum produced by a 6-inch grating of 21-foot radius, with ordinary photographic film in a plateholder curved to fit the focal surface of the spectrum. An exposure of a few seconds made near mid-totality shows only the prominences without chromospheric spectrum (Pl. I*a*).

The scale of this plate is 5.24 A per millimeter and is very nearly uniform over the region λλ 4861–3341. Three prominences appear, furnishing three spectra which were measured by Miss L. M. Ware and the writer. These lines and their measured wave-lengths, together with those observed by S. A. Mitchell[2] in the flash spectrum, are given in Table I. The table also gives the intensity I_P estimated on an arbitrary scale made to fit Mitchell's for the prominent lines, the intensity in the flash spectrum I_F, the height of the chromosphere in the flash spectrum, the element, excitation potential (E.P.), and the temperature classification. The intensities I'_P are taken from the work of Pannekoek and Doorn.[3] For the sake of completeness, the well-known lines in the visible spectrum and those observed by Burns[4] in the infra-red have been added. The magnesium doublet λ 5172 and λ 5183 is beyond the sensitive limit of the 1918 film, but shows weakly in the reproduction of Davidson and Stratton's plate[5] taken at the eclipse of January 14, 1926.

Table I includes all the lines of Mitchell's table having an intensity greater than 30, with the exception of λ 3234.49 Ti^+ (class IIIr) and λ 5316.67 Fe^+, both of intensity 30. No trace of λ 3234 can be found on the 1918 film, and λ 5316 does not seem to show as a prominence image on Davidson and Stratton's plate.

[1] *Annual Report of the Director, Mount Wilson Observatory*, 1918.

[2] *Astrophysical Journal*, **71**, 1, 1930.

[3] *Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam, Afdeeling Natuurkunde*, Sec. I, **14**, No. 2, 1930.

[4] *Lick Observatory Bulletin*, **10**, 67, 1920.

[5] *Memoirs of the Royal Astronomical Society*, **64**, 105, Plate 5, 1929.

TABLE I

Lines in the Prominence Spectrum

λ Prominence	λ Flash	I_P	I'_P	I_F	Height Flash	Element	E.P.	Temp. Class
8662.170	......	......	......	......	......	Ca^+	1.7	V
8542.132	......	......	......	......	......	Ca^+	1.7	V
8498.060	......	......	......	......	......	Ca^+	1.7	V
7065.185	5.20	......	......	6	1000	He	20.9	*Cr*
6678.149	8.10	......	......	20	2200	He	21.1	*Cr*
6562.816	2.80	......	1890	200	12,000	H_3	10.2	*Cr*
5875.650	5.64	......	138	80	7500	He	20.9	*Cr*
5183	3.58	......	......	40	2500	Mg	2.7	II
5172	2.65	......	......	30	2000	Mg	2.7	II
4861.344	1.50	200	512	200	8500	H_2	10.2	*Cr*
4713.20	3.15	2	......	5	5000	He	20.9	*Cr*
4571.80	2.00	1	......	35	2500	Ti^+	1.6	V
4554	4.11	0	......	50	2000	Ba^+	0.0	II
4549.61	9.63	1	......	50	2500	Ti^+-Fe^+	1.6	V
4541.71?	1.50	1	......	6d	700	Fe^+-Cr	2.8	III
4533.90	4.03	1	......	30	2500	Ti^+-Fe^+	1.2	V, III
4501.43	1.28	1	......	25	2500	Ti^+	1.1	V
4471.60	1.54	30	40	80	7500	He	20.9	*Cr*
4468.46	8.48	1	......	40	2500	Ti^+	1.1	V
4443.79	3.85	1	......	30	2500	Ti^+	1.1	V
4395.02	5.13	1	......	40	2500	Ti^+-V	1.1	II
4388.44	8.39	0	......	2	400	Fe	3.6	IV
4340.49	0.63	175	126	160	8000	H_5	10.2	*Cr*
4334.78*	4.84	1	......	2	500	La^+	......	V
4246.85	6.90	1	......	50	5000	Sc^+	0.3	III
4233	3.22	0	......	30	2200	Fe^+	2.6	
4226.46	6.74	1	......	40	5000	Ca	0.0	I
4215.45	5.70	4	3	60	6000	Sr^+-CN	0.0	II
4101.77	1.85	100	115	140	8000	H_6	10.2	*Cr*
4077.80	7.83	7	7	80	6000	Sr^+	0.0	II
4045.32	5.84	1	......	30	1800	Fe	1.5	II
4026.16	6.28	4	7	30	5000	He	20.9	*Cr*
3989.37	9.77	1	......	6	600	Ti-Fe	0.0	V
3970.08	0.25	......	......	120	8500	H_7	10.2	*Cr*
3968.48	8.70	1000	3310	175	14,000	Ca^+	0.0	II
3961	1.51	1	......	35	2000	Al	0.0	*Cr*
3953.47	3.03	1	......	4	600	Fe-Co-	3.0	IV
3947.59	7.66	1	......	6	600	Fe-Ti	2.8	IV
3933.61	3.90	1200	2720	200	14,000	Ca^+	0.0	II
3913.02	3.55	1	......	40	2500	Ti^+-Fe	1.1	V, III
3900.38	0.54	1	......	40	2000	Ti^+	1.1	V
3888.79	9.20	50	19	120	8500	H_8	10.2	*Cr*
3859.48	9.87	1	......	35	2500	Fe	0.0	I
3838.40	8.30	3	......	60	7000	Mg	2.7	II
3835.47	5.54	15	......	100	7000	H_9	10.2	*Cr*
3832.34	2.34	2	......	50	6000	Mg	2.7	II
3819.66	9.63	1	......	10	5000	He	20.9	*Cr*
3797.92	8.02	12	......	90	6000	H_{10}	10.2	*Cr*
3770.70	0.72	9	......	80	6000	H_{11}	10.2	*Cr*

* Possibly ghost of H_5.

TABLE I—*Continued*

λ Prominence	λ Flash	I_P	I'_P	I_F	Height Flash	Element	E.P.	Temp. Class
3761.56	1.33 1.88	9	......	70	6000	Ti^+	0.6 2.6	IV
3759.43	9.33	9	......	70	6000	Ti^+	0.6	IV
3749.81	50.25	5	......	70	6000	H_{12}	10.2	*Cr*
3746	5.78	0	......	30	2000	*Fe*	0.1	I A
3737	7.00	0	......	40	2000	Ca^+-*Ni* *Fe*	3.1 0.1	II, V I
3734.49	4.45	3	......	70	5600	H_{13}	10.2	*Cr*
3721.98	2.00	2	......	55	5600	H_{14}	10.2	*Cr*
3719.60	9.94	1	......	35	2000	*Fe*	0.0	I
3711.73	2.06	2	......	50	5000	H_{15}	10.2	*Cr*
3704.10	3.89	1	......	45	4000	H_{16}	10.2	*Cr*
3697.24	7.21	1	......	40	3500	H_{17}	10.2	*Cr*
3691.62	1.62	1	......	35	3000	H_{18}	10.2	*Cr*
3686.99	6.83	1	......	30	3000	H_{19}	10.2	*Cr*
3685.42	5.25	9	......	80	6000	Ti^+	0.6	IV
3383.76	3.84	2	......	25	2500	Ti^+-*Fe*	0.0	III, IV
3372.90	2.84	2	......	30	2500	Ti^+	0.0	III
3361.28	1.24	2	......	25	2500	Ti^+-Sc^+	0.0	I, III
3349.27	9.41	3	......	35	2500	Ti^+	0.0	II
3341.40	1.88	1	......	25	2000	Ti^+-*Fe*	0.6	II, III A

The lines fainter than 30 on Mitchell's scale that appear in Table I are shown in Table II. It will be noted that these are all spark lines of classes III–V (medium to highest energy-levels) or chromo-

TABLE II

LINES FAINTER THAN 30 IN THE FLASH SPECTRUM WHICH APPEAR IN PROMINENCES

Wave-Length	I_P	I_F	Element	E.P.	Temp. Class	Wave-Length	I_P	I_F	Element	E.P.	Temp. Class
7065.20	...	6	*He*	20.9	*Cr*	3989.77	1	6	*Ti-Fe*	0.0	V
6678.10	...	20	*He*	21.1	*Cr*	3953.03	1	4	*Fe-Co-*	3.0	IV
4713.15	2	5	*He*	20.9	*Cr*	3947.66	1	6	*Fe-Ti*	2.8	IV
4541.50	1	60	Fe^+-*Cr*	2.8	III	3819.63	1	10	*He*	20.9	*Cr*
4501.28	1	25	Ti^+	1.1	V	3383.84	2	25	Ti^+-*Fe*	0.0	III, IV
4388.39	0	2	*Fe*	3.6	IV	3361.24	2	25	Ti^+-Sc^+	0.0	I, III
4334.84	1	2	La^+	....	V	3341.88	1	25	Ti^+-*Fe*	0.6	II, III A

spheric helium. Generally speaking, the brighter lines in the prominences are also those which are the brighter in the chromosphere. Possibly λ 4334.84 is a ghost. It is peculiar that λ 4388.39 *Fe* shows when λ 4387.86 *He* does not, since the height of the latter line is

2000 km at the chromosphere; but repeated measurement fails to change the value given here.

The spectrum of the metallic prominences is not so well known as that of the ordinary kind. The lines which, in addition to those in Table I, commonly appear in the visual region are given by the Kodaikanal observers in their daily visual inspection of prominence spectra.[1]

Table III contains all the lines in the visual region of the flash spectrum brighter than 15 in Mitchell's table, except the three lines λλ 4934.08, 6141.77, and 6496.88, all belonging to ionized barium,

TABLE III

Additional Lines Which Appear in Metallic Prominences

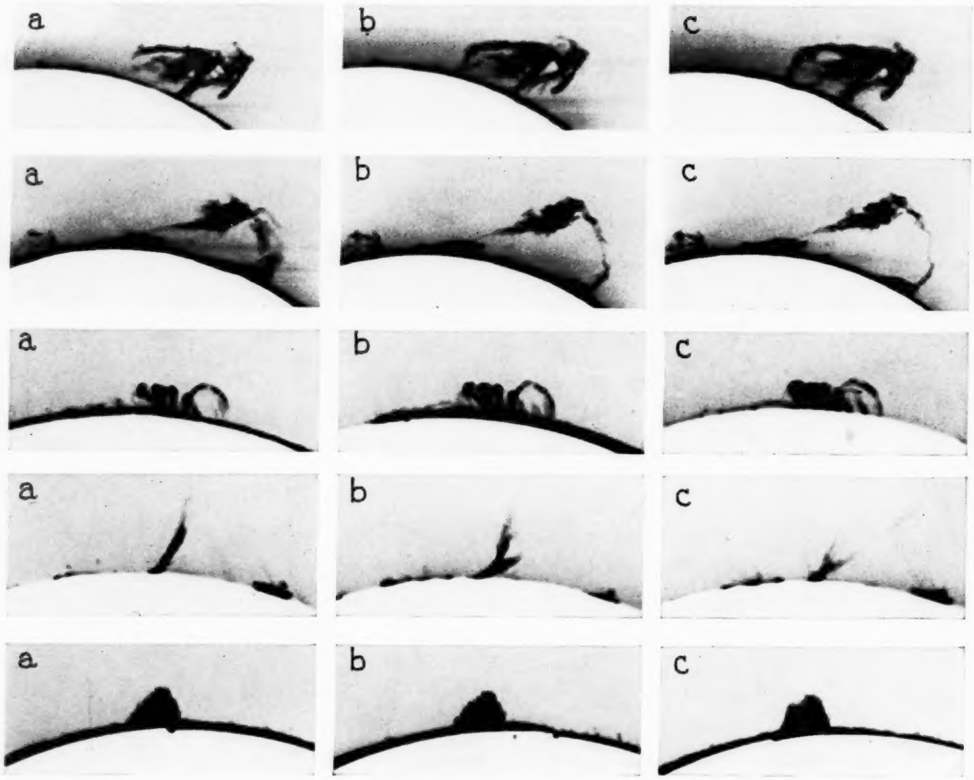
Wave-Length	I_F	Element	Wave-Length	I_F	Element
4923.96	30	Fe^+	5275.99	20	Fe^+-Cr
5015.68	2	He	5316.67	30	Fe^+
5018.44	25	Fe^+	5362.86	15	Fe^+
5167.35	18	Mg	5889.98	25	Na
5168.99	25	Fe^+-Fe	5895.99	20	Na
5172.65	30	Mg	6678.10	20	He-Fe
5183.58	40	Mg	7065.20	6	He
5234.63	15	Fe^+			

of intensity 25, 20, and 20, respectively. The lines of barium seem to be suppressed in the prominences; for example, the line λ 4554, of intensity 50 in the flash, is of intensity 0 in the prominences and just visible on the 1918 eclipse film. Helium, like hydrogen, seems to be present even in the lines that are very faint in the flash. In conclusion we may say that the spectrum of the prominences consists of the brighter lines of the flash spectrum and that metallic prominences are probably more brilliant only because the fainter lines are brought up by higher temperature, or greater density, or both. The occasional appearance of continuous spectrum[2] in these prominences is an indication of abnormal pressure. There is, then, no real spectral difference between the common and metallic prominences. Probably, if sufficiently long exposures could be given,

[1] *Kodaikanal Observatory Bulletins*, semiannual summary.

[2] C. A. Young, *The Sun* (1910), p. 225. This also shows in Davidson and Stratton's eclipse plate (*Memoirs of the Royal Astronomical Society*, **64**, 105, Plate 5, 1929).

PLATE II



Class 1

Class 2

Class 3

Class 4

Class 5

TYPES OF PROMINENCES, SHOWING STRUCTURAL CHANGES at INTERVALS OF A FEW MINUTES (G.C.T.)

Class 1, active type, February 28, 1929:
a) $19^{h}15^{m}$; (*b*) $19^{h}34^{m}$; (*c*) $19^{h}45^{m}$

Class 2, eruptive type, April 5, 1930:
(*a*) $17^{h}08^{m}$; (*b*) $17^{h}13^{m}$; (*c*) $17^{h}19^{m}$

Class 3, spot type, August 19, 1927:
(*a*) $17^{h}43^{m}$; (*b*) $17^{h}47^{m}$; (*c*) $17^{h}51^{m}$

Class 4, tornado type, July 5, 1928:
(*a*) $17^{h}11^{m}$; (*b*) $17^{h}17^{m}$; (*c*) $17^{h}24^{m}$

Class 5, quiescent type, August 21, 1930:
(*a*) $16^{h}45^{m}$; (*b*) $17^{h}00^{m}$; (*c*) $17^{h}06^{m}$

the spectrum of the prominences would be much like the flash, except that some of the lines, like those of helium, would be brighter, while those of elements like barium would be relatively fainter. This behavior suggests that the forces which expel prominences from the chromosphere sift out the heavier elements such as barium.

FORMS OF PROMINENCES

The forms of prominences as they appear at the limb of the sun may be divided in order of their approximate frequency into five classes: (1) *active* prominences, which appear to be torn apart by an area of attraction or by a neighboring sun-spot; (2) *eruptive* prominences, which ascend in a more or less vertical direction; (3) *spot* prominences, which often have the appearance of closed loops of a fountain or of spikes with external wings—generally their appearance is best described by the word "splash"; (4) *tornado* prominences, which appear like vertical spirals or tightly twisted ropes; (5) *quiescent* prominences, which show only minor changes from minute to minute.

Plate II illustrates the five prominence types, showing their development during approximately the same intervals of time.

In general we may regard all prominences as "active," the distinction among the five classes outlined here being in the degree and kind of activity. In the strict sense of the word there seems to be no such thing as a "quiescent" prominence. Those which appear to be the best examples of this class show structural changes easily observable with the blink comparator in spectroheliograms taken at intervals of 4 or 5 minutes, provided the atmospheric definition was sufficiently good.

Classes 1 and 2 are closely associated; a single individual often exhibits both phases simultaneously or passes from the active into the eruptive state. Although a spot may or may not be connected with classes 1 and 2, both these forms may be associated individually or collectively with class 3. We shall consider these generalizations in what follows.

DIMENSIONS OF PROMINENCES

The three-dimensional forms of prominences may be studied by comparing their outlines as they pass over the sun's disk and ap-

pear in projection at the limb. Prominences show on the disk as the well-known absorption markings, or, in the case of metallic prominences, as bright markings. They generally appear as long streaks, usually somewhat curved, and, when radial or near the center of the disk, we see them in plan and may measure their thickness. A considerable number of such cases was selected from the routine series of spectroheliograms taken with the 13-foot spectroheliograph during the last sun-spot cycle and measured with a microscope having a simple scale in the field. The range in thickness is surprisingly small, generally from 6000 to 12,000 km, although some examples may measure 15,000 km. The length is quite variable. Very few prominences are shorter than 60,000 km, and a length of 600,000 km is unusual, although cases have been found where a broken line of prominences extended over more than one-fourth the circumference of the sun. D'Azambuja,[1] in charting the prominences in projection on the sun, found several instances of this kind. The height is also quite variable, 75,000–100,000 km being not uncommon. The highest yet recorded was a fragment of a class 2 prominence 929,000 km above the chromosphere, observed by T. Royds[2] on November 19, 1928.

We may regard the three-dimensional form of a prominence, then, as much like that of a thin sheet of flame issuing from the familiar fish-tail burner of the laboratory. The sheet of incandescent gas stands on one edge, usually not in contact with the chromosphere throughout its entire length, but raised above it a few thousand kilometers and connected with it by columns, like the roots of a tree. These columns are frequently staggered along the line beneath the prominence and generally spread out at the surface of the chromosphere. This description is drawn from an examination of the larger prominences; the smaller ones often seem to be without the connecting columns and simply stand on edge upon the chromosphere or above it. The atmospheric definition is seldom good enough to make an examination of the smaller objects satisfactory.

Representative dimensions are perhaps a thickness of 10,000 km, a length of 200,000 km, and a height of 50,000 km, which imply a vol-

[1] *Op. cit.*, **6**, Fascs. 1–4, 1928–1930; see rotations Nos. 900 and 920, for example.

[2] *Monthly Notices of the Royal Astronomical Society*, **89**, 255, 1928.

ume ninety-three times that of the earth. The largest prominence known to the author is that of class 2 observed[1] on May 29, 1919. We have no value of the thickness later than about three weeks preceding the eruption (which took place on the east limb), when it averaged about 8000 km. The supposition that at the time of the eruption the thickness did not exceed 12,000 km would give a volume four hundred times that of the earth.

MASSES OF PROMINENCES

The mass of a prominence is difficult to estimate largely because of the uncertainty as to the fraction of the atoms which are radiating. The density of the radiating atoms per cubic centimeter was determined for three prominences at the eclipse of June 29, 1927, by Pannekoek and Doorn.[2] To obtain the volume of the prominence, they assumed the thickness to be the same as the tangential extent. While this estimate is presumably valid for the small prominence *b*, it is probably twenty fold too great for prominence *a* (200,000 km reduced to 10,000 km). This makes the density of prominence *a*, 3.8 atoms in the H_5 state, or 32×10^{11} atoms of hydrogen per cubic centimeter at large, almost the same as the density for prominence *b*. For Ca^+, Pannekoek and Doorn obtained for each prominence, with the foregoing correction, 2.6 and 1.6 atoms, respectively, in the $2S-2P_1$ and $2S-2P_2$ states. As all the Ca^+ atoms are supposed to take part in the radiating process, the admixture of calcium in the prominence is insignificant. We know little about helium, therefore we must, for the present, consider the prominence to be made of hydrogen of atomic density comparable with that computed above. Both *a* and *b* were very weak prominences, while *c*, which was outside their photometric range, was more nearly representative, and, judged from their estimates of intensities in the strontium lines, the ratio is about 6. This would indicate a density of 2×10^{13} atoms of hydrogen per cubic centimeter in a prominence of ordinary kind. This figure is, of course, controlled by the large factor of proportionality 1.2×10^{-12} between the excited H_5 atoms and the total number at 5500° K, which is to a great extent uncertain. Using, however, the foregoing density and the mass of a hydrogen atom, 1.7×10^{-24}

[1] *Loc. cit.* [2] *Loc. cit.*

gm, we find the mass of the representative prominence 10,000 km thick, 200,000 km long, and 50,000 km high to be 3.4×10^{18} gm, about the mass of a cube of water 15 km on an edge. The mass of the largest prominence on record, that of May 29, 1919, would be about four times as much.

DISTRIBUTION OF THE ELEMENTS IN PROMINENCES

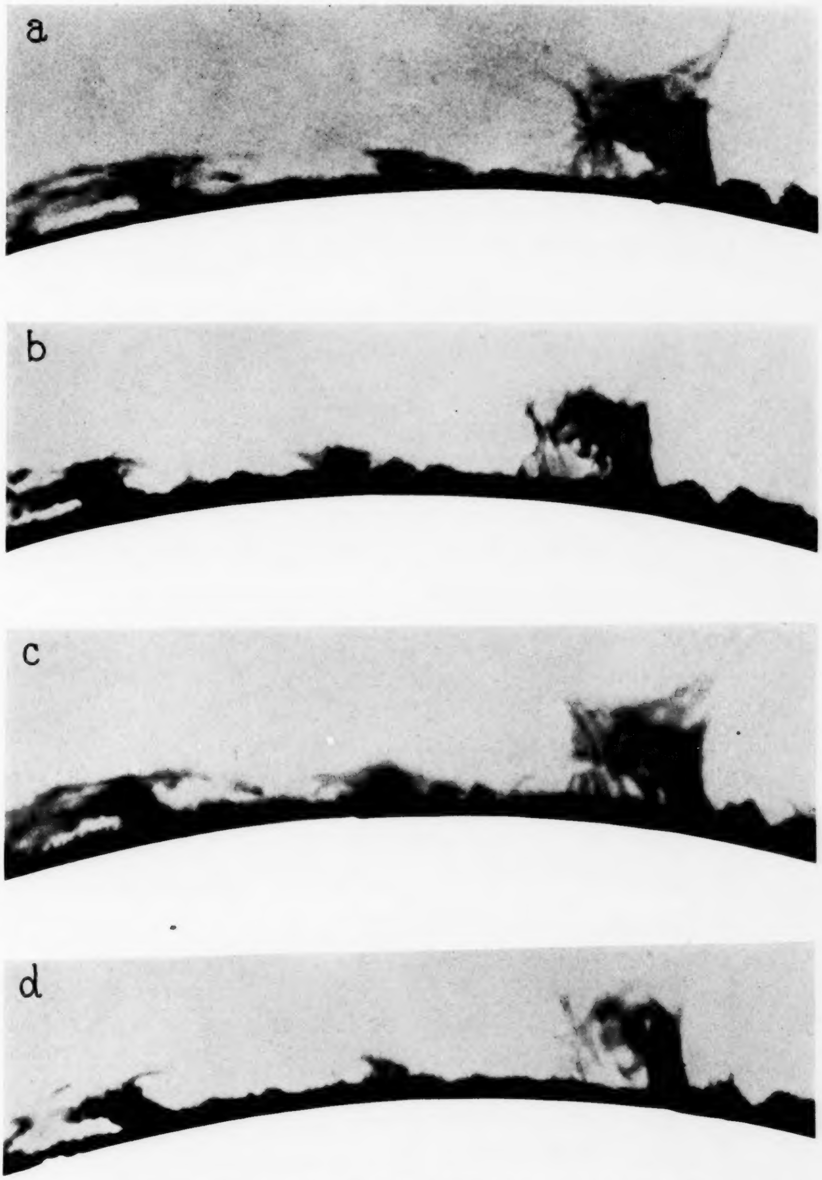
The ideal method of studying the distribution of the elements in prominences would be by means of objective-grating spectra taken at an eclipse, as shown in Plate I*a*. As indicated in Table I, the range of intensity covered by the H and K lines of calcium, the first few lines of the Balmer series of hydrogen, and the lines of the other elements is so great that several widely differing exposures would be necessary. The film of Plate I*a* indicates, however, that the principal features of the prominences shown in the lines measured which were brighter than about 5 (column headed I_P, Table I) were substantially the same. The other lines were too faint to be sure of the form. This statement applies to the general outline of the prominence, and not to the streamers or other fainter details.

Without an eclipse we are confined to a comparison of calcium with hydrogen and possibly helium. The writer has used both photographic and visual methods. Plate III shows four spectroheliograms taken alternately in the $H\alpha$ line of hydrogen and the H and K lines of calcium, which confirm the testimony of the eclipse film in Plate I*a*. They are of the prominence of August 6, 1931, in the active stage just before the eruption began. The first exposure was made by the author at the Yerkes Observatory in the H line of calcium; the others were made a few minutes later at Mount Wilson by S. B. Nicholson in $H\alpha$ and K_2. It will be noted that the streamers in the active prominences shown here are not so numerous or so intense in hydrogen as in calcium. Since this difference may be a matter of photographic contrast, it was thought advisable to study the question by comparing drawings made in $H\alpha$ with spectroheliograms made simultaneously in K_2.

For this purpose the spectrohelioscope[1] was used with Anderson's rotating prisms. This instrument includes a 6-inch bright first-order

[1] Hale, *Mt. Wilson Contr.*, No. 388, Pl. XIX; *Astrophysical Journal*, **70**, 265, Pl. XIV, 1929.

PLATE III



Calcium
H

Hydrogen
Hα

Calcium
K

Hydrogen
Hα

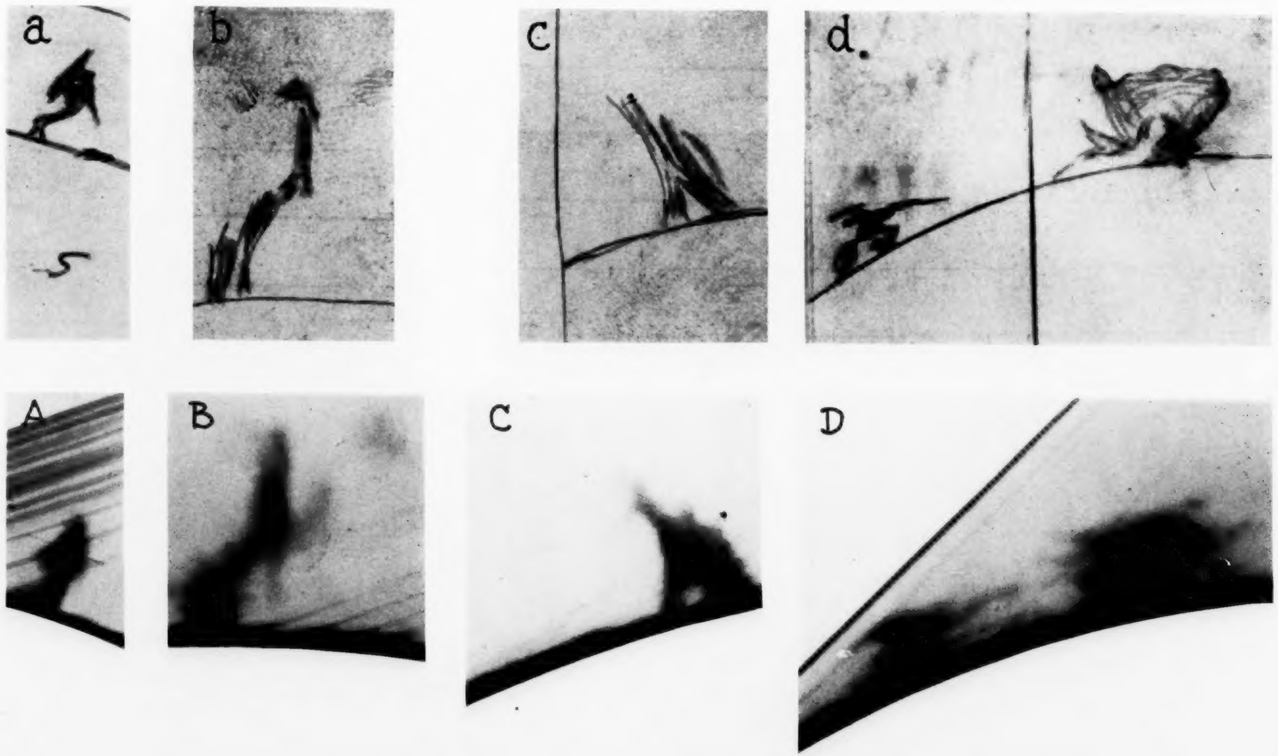
PHOTOGRAPHS OF PROMINENCE (No. 35) OF AUGUST 6, 1931, MADE BEFORE THE ERUPTION BEGAN, ALTERNATELY IN THE LIGHT OF CALCIUM AND HYDROGEN

(*a*) Yerkes Observatory at $14^h22^m.7$, (*b*) Mount Wilson at 14^h27^m, (*c*) Mount Wilson at 14^h37^m, (*d*) Mount Wilson at 14^h44^m, G.C.T.

PLATE IV

Hydrogen
$H\alpha$

Calcium
K



Drawings of Prominences (a,b,c,d) as Seen with the $H\alpha$ Line of Hydrogen Compared with Photographs (A,B,C,D) Made in the K Line of Calcium

(aA) Dec. 16, 1930; (bB) Dec. 19, 1930; (cC) Jan. 12, 1931; (dD) Jan. 26, 1931

eclipse of June 8, 1918, radiating from a center of attraction between the two active prominences on the western limb of the sun, strongly suggest lines of force about the pole of a magnet. A close examination of a photograph of that eclipse taken by Miss M. R. Calvert and Professor E. E. Barnard with a 60-foot focus lens shows that the coronal streamers near the stronger prominence (see the H and K images of Plate I*a*) have exactly the same curvature as the prominence streamers, which were moving into the center of attraction at a rate of 100 km/sec., a velocity obtained by measuring two of these eclipse plates in the blink comparator. The characteristic curving of coronal streamers about prominences of all types to form the well-known arches is also an argument for a field of force about a prominence. Such a coronal disturbance[1] appeared above the great prominence of May 29, 1919, where the streamers arranged themselves in an arch whose shape conformed closely to that of the prominence. If the corona is, indeed, composed largely of electrons, the ionized calcium atoms of large prominences must certainly disturb it.

HEIGHT OF THE CHROMOSPHERE IN $H\alpha$

The height of the chromosphere in $H\alpha$ was measured with the spectroheliоscope on several occasions in February and March, 1931. The method depended on the following phenomenon: if we observe the sun with the spectrohelioscope set for $H\alpha$ and then shift the line off the second slit with the line-shifter so that we see the sun in the continuous spectrum of a near-by wave-length, the radius of the image is decreased by the thickness of the $H\alpha$ chromospheric layer. With the instrument just described the effect is very striking.

The measurements were made with a filar micrometer and projecting doublet, which transferred the image to an accessible position. The line-shifter was adjusted to give minimum light, indicating that the $H\alpha$ line was centered on the second slit. The position of the limb in the field was then adjusted by rotating the plane-parallel glass plate which operates as a fine motion in right ascension until the limb came in contact with the wire of the micrometer. The continuous spectrum was then brought on the second slit by quickly

[1] Drawings of the corona from photographs, communicated by the Astronomer Royal, *Memoirs of the Royal Astronomical Society*, **64**, Appendix, 1929.

moving the line-shifter, a neutral-tint shade glass was thrown over the eyepiece to reduce the intensity to that previously observed, and the micrometer wire was again set on the limb. The difference in readings was the thickness of the chromosphere, expressed in revolutions of the screw. The experiment was repeated on the other limb to eliminate the systematic error of image drift. This was small, however, as the whole measurement required only a few seconds. The instrument was calibrated by observing with a chronograph the time required for the limb to drift over the micrometer wires, the coelostat clock having been stopped. The value of 1 revolution of the screw was thus found to be $4''.44$.

Observations were made on days of good definition only—February 25 and March 6, 7, and 9, 1931. The mean value of the thickness of the chromosophere in $H\alpha$ was $7''.6$, which is equivalent to 5500 km. This value is less than half that found by Mitchell[1] from flash spectra, but only about 19 per cent less than that observed by G. Abetti[2] with a visual spectroscope. The spectrohelioscope probably gives a minimum value, since the wire is set at the base of the rough outline of the chromosphere.

ERUPTIVE PROMINENCES (CLASS 2)

A study of all the available data on eruptive prominences on which four or more measurements were made has been published in a previous paper.[3] Of this collection of 24 eruptive prominences, 11 were spectroheliographic results in Ca^+, either H or K, and 13 were visual measurements, usually by the method of transits, in the $H\alpha$ line of hydrogen. The principal results were: (1) eruptive prominences move with uniform motion, the velocity increasing suddenly at intervals, and (2) the maximum velocity observed was 400 km/sec.

The principle of uniform motion expressed by (1) has always been a stumbling-block to those seeking to explain the motions of eruptive prominences on the theory of light-pressure[4] or otherwise.[5]

[1] *Loc. cit.*

[2] *Handbuch der Astrophysik*, **4**, 139, 1929; see also *Osservazioni e memorie del R. Osservatorio Astrofisico di Arcetri*, 1922 ff.

[3] *Publications of the Yerkes Observatory*, **4**, Part III, 1925.

[4] S. R. Pike, *Monthly Notices of the Royal Astronomical Society*, **88**, 3 and 635, 1927–1928.

[5] N. T. Bobrovnikoff, *Astrophysical Journal*, **74**, 157, 1931.

After allowing the matter to rest about ten years, I began to wonder if the observations themselves might be at fault, as suggested by Pike,[1] for example. To get at the facts in the case, we may (1) review the best examples already given (i.e., those best observed in respect to the character of the motion), (2) examine the results published by other observers, (3) obtain new material for this purpose, and (4) test the impartial character of the measurements by having them checked by other investigators. We shall consider these points in the order named.

1. *Examples already given.*—For simplicity, the numbering previously used in identifying the various examples is retained. The examples showing the uniform character of motion in the most indisputable manner are illustrated in Figure 1. Of these, Nos. 1, 2, and 3 are spectroheliographic results in the H line of calcium obtained by the author; Nos. 16 and 18 are visual measurements made by J. Fényi at the Haynald Observatory; and No. 23 is by J. B. Coit, of Boston University—all in the $H\alpha$ line of hydrogen.

Number 1, the prominence of May 29, 1919, is that in which the phenomenon of uniform motion accelerated at intervals was first observed by the author. The curve represents the motion of the center of the prominence, i.e., the march of the average of the heights of the top and bottom above the chromosphere. It seems to make little difference in the result whether the top, center, bottom, or some particular feature which endures long enough is used as an origin of measurement of the height; the same kind of curve is always obtained, although the velocity may differ a little, as might be expected on account of the motions of parts of the prominence relative to one another during the eruption, generally an expansion with ascent.

Number 2 is the prominence of July 15, 1919, the measurements being made on the middle of the expanding crest. This prominence had the form of an expanding arch, and the center of the crest was easily measured and followed from exposure to exposure.

Number 3 is an interesting case. This prominence had the form of a cloud of smoke shot from a gun, at an angle of 50° to the vertical. The measurements were made on the end of the column in the direc-

[1] *Op. cit.*, pp. 21–22.

tion of motion. On coming to Mount Wilson, I found that two spectroheliograms had been taken with the 13-foot spectrohelio-

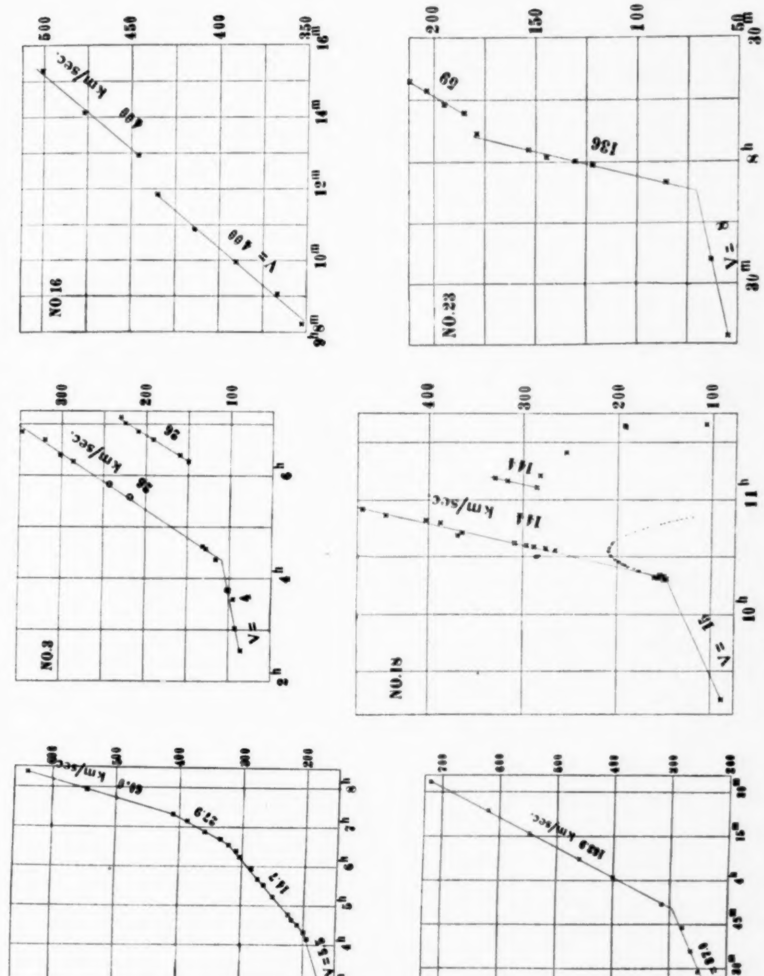


FIG. 1.—Motions of eruptive prominences (No. 1) May 29, 1919; (No. 2) July 15, 1919; (No. 3) September 8, 1919; (No. 16) September 20, 1893; (No. 18) December 24, 1894; (No. 23) June 11, 1895. Abscissae are times of observation (G.M.T.); ordinates, height of prominence; unit = 1000 km.

graph, which, upon measurement, gave the two points, indicated by the circles in the plot, close to the straight line already obtained at the Yerkes Observatory.

All these motions are so large that a simple millimeter scale is sufficient to measure them. On the plates made with the Rumford

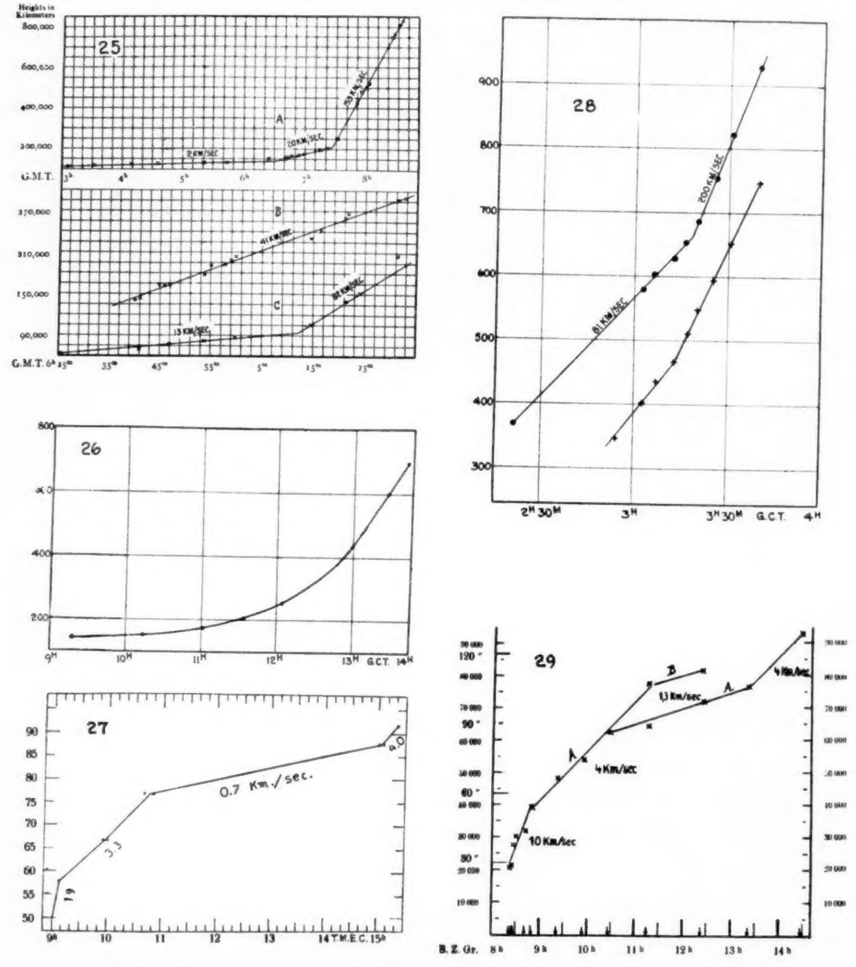


FIG. 2.—Motions of eruptive prominences (No. 25) October 8, 1920; (No. 26) May 14, 1925; (No. 27) May 14, 1928; (No. 28) November 19, 1928; (No. 29) March 18, 1929. Abscissae are times of observation (G.C.T. except No. 25, which is G.M.T., and No. 27, which is European Central Time); ordinates, heights of prominence; unit = 1000 km.

spectroheliograph at the Yerkes Observatory, the motions in Nos. 1 and 2 covered about 88 mm, and those in No. 3 about half as much. Numbers 16 and 18 are plots of the measures as published by

Fényi. For No. 23, Coit gave the heights obtained by using the mean apparent solar diameter. These have been corrected by applying the constant factor necessary to reduce them to the actual apparent diameter. I think it must be admitted that for none of these cases could a smooth curve other than a straight line be drawn which would do justice to the observations. Perhaps the most questionable case is No. 1, but even here there would have to be a straight section between 4^h and 6^h30^m G.M.T., since in this part the observations give a well-determined line.

2. *Observations published since 1920.*—The instances cited under (1) are from the list of all available data up to 1920. Results published since that time are numbered in continuation of the series already given. They consist of No. 25, the eruptive prominence of October 8, 1920, observed by O. J. Lee[1] with the Rumford spectroheliograph at the Yerkes Observatory; No. 26, on May 14, 1925, by D'Azambuja[2] at Meudon; No. 27, on May 14, 1928, by Abetti[3] at Arcetri; No. 28, on November 19, 1928, by Royds[4] at Kodaikanal; and No. 29 on March 18, 1929, by W. Brunner[5] at Zurich. The observed heights of the prominences and the times of observation as given by the observers are collected in Table IV; the plots are shown in Figure 2. A plot of No. 25 was given by Lee, but no table of times and heights. To supply these, I have read them from the plot, the times being checked from the observing book at the Yerkes Observatory. For No. 26 a table was published but no plot; and for No. 28, by Royds, only the half-tone prints and three stated heights were given. Dr. Royds has kindly furnished me with contact copies of the original negatives and data giving the exact times of exposure. The plot in Figure 2 shows the heights of the crest and of the base of the moving cloudlike prominence which I have measured.

In Lee's prominence, No. 25, there can be no question that the

[1] *Astrophysical Journal*, **53**, 310, 1921.

[2] *L'Astronomie*, **40**, 64, 1926.

[3] *Osservazioni e memorie del R. Osservatorio Astrofisico di Arcetri*, No. 45, 36, 1928.

[4] *Loc. cit.*

[5] *Astronomische Mitteilungen der Eidgenössischen Sternwarte in Zürich*, No. 121, 7, 1929.

TABLE IV

COLLECTED DATA ON ALL OBSERVATIONS OF ERUPTIVE PROMINENCES* OBTAINED SINCE 1920

Identity and Remarks	G.C.T. of Observation	Height in Thousand Kilometers
25. October 8, 1920. Observed by Lee at the Yerkes Observatory. Spectroheliograph in H line of Ca^+. Lat. 24° S. on the east limb. No sun-spot near. *Astrophysical Journal*, **53**, 310, 1921. No table given. Heights and times read from Lee's plot. The times of observation have been checked against the observing book to obtain the decimal of minutes. Top of the prominence was measured by Lee. For detailed analysis of other points see reference. V = 2, 20, and 155 km/sec.	$15^h04^m.5$	110
	32.0	115
	16 08.0	125
	35.6	125
	17 22.8	130
	42.5	135
	18 23.8	150
	40.8	150
	44.7	160
	45.8	170
	53.6	170
	59.7	175
	19 14.2	199
	21.0	201
	31.0	250
	49.3	425
	53.0	480
	57.9	500
	20 01.8	520
	25.2	750
	26.5	770
	31.5	810
	33.2	831
26. May 14, 1925. Observed by D'Azambuja at Meudon. Spectroheliograph in K line of Ca^+. Lat. 35°–48° S. on the west limb. No sun-spot near. *L'Astronomie*, **40**, 64, 1926; see table, p. 65. Accelerated motion. V varies from 4 to 122 km/sec.	9 18	140
	10 13	152.5
	11 01	175
	34	205
	12 05	253
	58	435
	13 27	600
	43	695
27. May 14, 1928. Observed by Abetti at Arcetri. Spectroheliograph in K line of Ca^+. Typical sun-spot prominence connected with the large spot leading the group, Mt. Wilson, No. 3346. Lat. 14° S. on the west limb. *Osservazioni e memorie del R. Osservatorio Astrofisico di Arcetri*, No. 45, 36, 1928. V = 19, 3.3, 0.7, and 4.0 km/sec.	8 00	50
	07	58
	30	
	55	66.7
	9 00	66.7
	40	76.7
	50	76.7
	10 04	
	14 00	87.6
	05	87.6
	10	
	20	91.7

* For data previous to this date see *Publications of the Yerkes Observatory*, **3**, Part IV, 210, 1925.

TABLE IV—*Continued*

Identity and Remarks	G.C.T. of Observation	Height in Thousand Kilometers
28. November 19, 1928. Observed by Royds at Kodaikanal. Spectroheliograph in K line of Ca^+. Lat. 71°–72° S. on the west limb. No spot near. Only three measurements given. Others obtained by measuring copies of the original plates furnished by Royds. *Monthly Notices of the Royal Astronomical Society*, **89**, 255, 1929. V=81 and 200 km/sec.	$2^h21^m.4$	364
	54.6	348
	57.8	371
	3 02.8	580, 404
	06.8	603, 436
	12.7	626, 464
	16.7	650, 510
	20.7	684, 545
	25.8	754, 592
	31.3	812, 650
	39.6	928, 742
29. March 18, 1929. Observed by Brunner at Zurich. Visual in *Hα* line of hydrogen. Lat. 10° S. on the east limb. No sun-spot. Times are given, heights read from Brunner's plot. *Astronomische Mitteilungen der Eidgenössischen Sternwarte in Zurich*, No. 121, 7, 1929. V=10, 4, 1.3, and 4 km/sec.	8 22	20.5
	25	21
	27	27.5
	30	30
	42	31
	50	39
	9 22	48
	54	53.5
	10 27	62
	11 15	77.5, 64
	12 23	81 , 71
	13 21	76
	14 27	92.5
30. June 23, 1924. Observed by Lewis Humason. 13-foot spectroheliograph at Mount Wilson. Not published. Measures by the author. K line of Ca^+. Lat. 58° N. on the east limb. No spot. V=43 and 73 km/sec.	15 40.0	222
	45.0	222
	51.0	222
	16 47.0	181
	51.5	195
	58.1	200
	17 03.2	222
	08.6	228
	13.1	250
	18.0	261
	18 01.3	395, 195
	03.7	417, 222
	06.5	434, 245
	16.0	453, 289
	20.0	473, 306
31. June 18, 1929. Observed by J. Hickox. 13-foot spectroheliograph at Mount Wilson. Not published. Measures by the author. K line of Ca^+. Appeared over large spot, leader of group, Mt. Wilson, No. 3726. Lat. 10° S. on the east limb. Arose at a point 12° S., sending streamers over the spot to a point on the solar equator. V=3, 19, and 37 km/sec.	16 35	68.2
	46	68.2
	56	68.2
	17 35	76.4
	54	81.9
	18 50	90.1
	19 32	109.2
	50	133.8
	20 10	155.6
	23	169.3

TABLE IV—*Continued*

Identity and Remarks	G.C.T. of Observation	Height in Thousand Kilometers
31.—*Continued*	20^h32^m 46 56 21 04 27	185.6 221.1 240.2 245.7 300.3
32. February 6, 1930. Observed by Hickox. 13-foot spectroheliograph at Mount Wilson. Not published. Measures by the author. K line of Ca^+. Appeared in Lat. 29° N. on the east limb. No spot near prominence. V = 21 km/sec.	17 44 50 56 18 18 19 20	122 125 139 158 236
33. April 10, 1931. Observed by Hickox. 13-foot spectroheliograph at Mount Wilson. Not published. Measures by the author. K line of Ca^+. Appeared in Lat. 35° N. on the west limb. No spot near. Measures of both crest and base are given. V = 86 km/sec.	17 11 18 21.5 41.4 47.8 18 11	189, 111 197, 125 217, 131 295, 206 320, 242 420, 330
34. August 22, 1930. Observed by Pettit with the Rumford spectroheliograph attached to the 40-inch telescope at the Yerkes Observatory. H line of Ca^+. Appeared in Lat. 24° N. on the west limb. No spot near. Measures made on a small floating cloud which became detached from the head. V = 4 and 25 km/sec.	18 55.5 19 11.4 14.0 19.3 23.8 26.7 29.8 34.3 36.5 39.7 41.8 49.3 54.3 20 00.1 02.5 11.9 16.3 19.0 21.3	53.6 57.5 58.9 59.4 60.9 66.2 68.2 76.9 79.4 85.2 87.7 93.5 98.4 108.6 110.1 114.4 117.9 122.2 124.7
35. August 6, 1931. Observed by Pettit with the Rumford spectroheliograph with the assistance of H. S. Pettit and P. C. Keenan at the Yerkes Observatory. Measures by L. M. Ware, S. B. Nicholson, E. Hubble, and the author. The means of the measurements by all four observers are given in the table. Prominence appeared in Lat. 6° S. on the west limb. No spot or prominent surface marking near. V = 5, 19, 74, 126, and 105 km/sec.	14 22.7 49.2 54.3 59.6 15 07.4 12.7 16.9 31.5 36.0 40.0 44.7 48.9	49.2 47.4 47.9 47.4 47.9 48.4 50.8 60.2 63.3 63.3 63.3 66.7

TABLE IV—*Continued*

Identity and Remarks	G.C.T. of Observation	Height in Thousand Kilometers
35.—*Continued*	$15^h52^m.8$	67.9
	58.5	65.4
	16 03.9	70.0
	07.8	70.5
	11.8	71.5
	18.5	77.1
	23.3	82.3
	29.0	89.2
	32.8	94.8
	37.6	100.8
	42.5	103.1
	46.2	108.4
	50.6	113.3
	56.8	120.0
	17 00.7	124.6
	04.7	129.5
	07.6	135.1
	13.0	139.2
	16.8	145.8
	25.5	171.2
	30.4	180.5
	34.3	193.5
	38.8	212.3
	42.5	232.0
	46.3	247.4
	52.8	287.2
	56.0	312.5
	58.9	336.3
	18 05.7	387.2
	08.9	410.5
	11.7	427.1
	16.3	462.7
	19.1	480.6
	21.7	497.5
	30.1	530.6
	33.6	554.2
	36.4	570.0
	40.5	596.0
	43.0	605.0
	45.7	620.4

motion (*a*) was uniform with two sudden increases. Lee's detailed analysis of other parts of the prominence shows the same feature (*B*, *C*, *D*, *E*, *F*), *E* and *F* (see reference) evidently being affected by fading. Prominences Nos. 27, 28, and 29 also show uniform motion. Number 27 probably had more of the features of a class 3 prominence of the fountain type, and through the later stage of the eruption may have been moving nearly parallel to the solar surface.

Number 29 in its last stages doubtless was affected by fading. Number 26 seems to be a clear case of accelerated motion, but the observations were made so far apart that we cannot be sure. The average interval between observations is 38 minutes, with one of nearly an hour. The frequency of the breaks in the well-observed curves is of this order.

3. *New material.*—This consists of No. 30, taken by Lewis Humason with the 13-foot spectroheliograph[1] at Mount Wilson, June 23, 1924; No. 31, June 18, 1929; No. 32, February 6, 1930; and No. 33, April 10, 1931—all taken with the same instrument by Joseph Hickox; No. 34, August 22, 1930, and No. 35, August 6, 1931, taken at the Yerkes Observatory with the Rumford spectroheliograph by the author, at the kind invitation of Professor Frost. The plots are shown in Figure 3. The 13-foot spectroheliograms themselves were on a scale of 27,800 km per millimeter, and those with the Rumford spectroheliograph, 7800 km per millimeter. Plate V shows three exposures each of Nos. 30, 32, 33, and 34, while Plate I*b* shows twelve stages of No. 31; Plate VI shows seven stages of No. 35 taken in the H line of calcium and a comparative study of this prominence in the *Hα* line of hydrogen with the spectrohelioscope. Plate III shows No. 35 in *Hα* and in H and K just before the eruption began.

The measurements in nearly all cases refer to the highest point on the prominence. For Nos. 33 and, in part, 35 (Hubble's measures between $16^h7^m.8$ and $17^h7^m.6$), other points which could be identified in successive exposures have also been measured. The results are given in Table IV and in Figures 3 and 4. An unfortunate break in the series of exposures of No. 30 was due to an attempt to change objectives, which resulted in a change in orientation of the solar image, thus throwing the prominence out of the field. This leaves the curve somewhat doubtful in its middle part. The ends, however, are so well observed that there can be little question as to the character of the motion and velocity. Numbers 32 and 33 are represented by only a few points, but these are fairly well distributed, and, fortunately, no change in velocity occurred in either series.

[1] For a brief description of the 13-foot spectroheliograph see Hale, *Publications of the Astronomical Society of the Pacific*, **27**, 233, 1915.

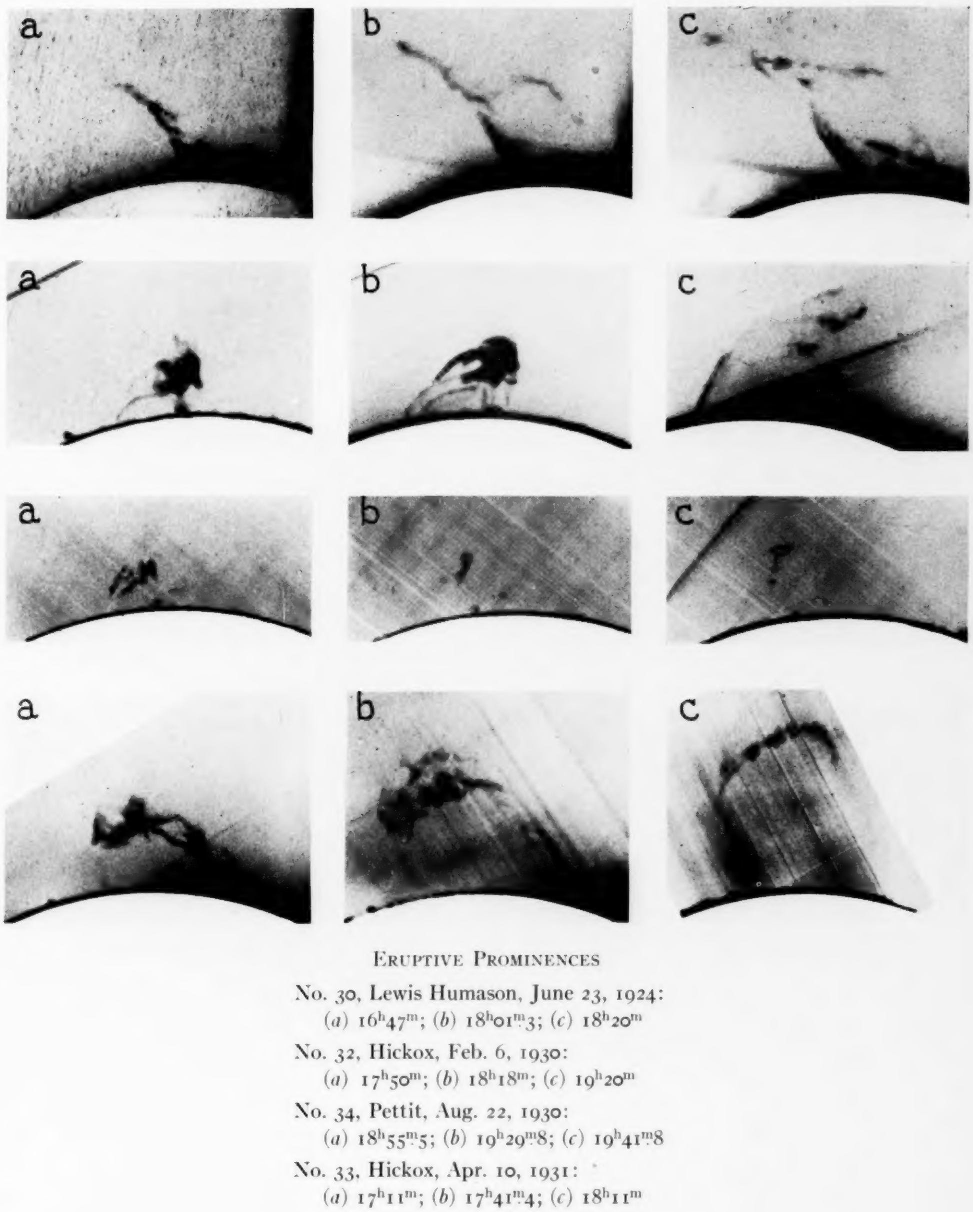
PLATE V

No. 30

No. 32

No. 34

No. 33



ERUPTIVE PROMINENCES

No. 30, Lewis Humason, June 23, 1924:
(*a*) $16^{h}47^{m}$; (*b*) $18^{h}01^{m}.3$; (*c*) $18^{h}20^{m}$

No. 32, Hickox, Feb. 6, 1930:
(*a*) $17^{h}50^{m}$; (*b*) $18^{h}18^{m}$; (*c*) $19^{h}20^{m}$

No. 34, Pettit, Aug. 22, 1930:
(*a*) $18^{h}55^{m}.5$; (*b*) $19^{h}29^{m}.8$; (*c*) $19^{h}41^{m}.8$

No. 33, Hickox, Apr. 10, 1931:
(*a*) $17^{h}11^{m}$; (*b*) $17^{h}41^{m}.4$; (*c*) $18^{h}11^{m}$

Number 31 was fairly well observed, two breaks occurring in the velocity-curve.

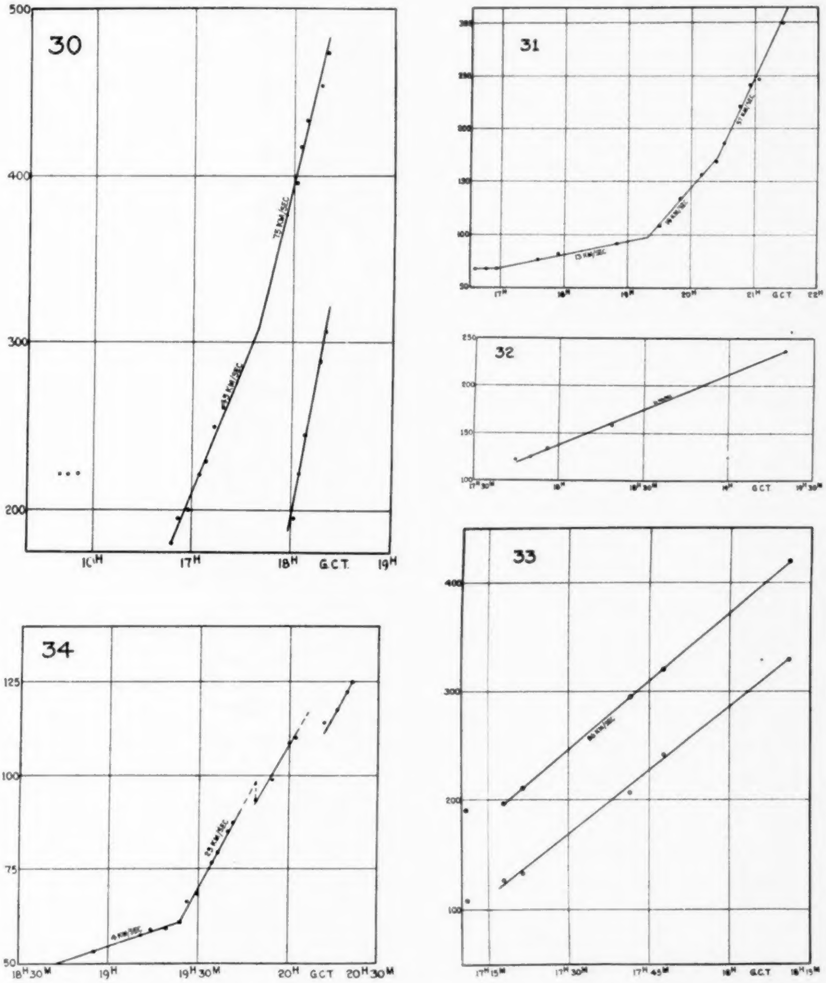


FIG. 3.—Motions of eruptive prominences (No. 30) June 23, 1924; (No. 31) June 18, 1929; (No. 32) February 6, 1930; (No. 33) April 10, 1931; (No. 34) August 22, 1930. The abscissae are times of observation (G.C.T.); ordinates, heights of prominence; unit = 1000 km.

Number 34, observed by the author at the Yerkes Observatory, is a small prominence (Plate V) rising to only 125,000 km, but on the large scale of the 40-inch telescope it could be measured easily.

It appeared on the west limb of the sun in latitude 42° N. as an active prominence. In the late morning it finally developed into an expanding arch, the south end rising, and toward noon eruptive characteristics appeared. Plate V shows three stages of the prominence during the eruptive state. Exposures were made at the average rate of one for every 4.8 minutes.

The chief difficulty with most prominence observations is that only a few exposures are made, and those at intervals too great to be sure of the character of the changes taking place. If 15 or 20 minutes elapse between observations, a break in the velocity-curve may occur; and in an interval of an hour, two such breaks are possible; 5-minute intervals are about right, or better those of 3 minutes, if the instrument can be operated at such a speed. To accomplish this, an additional observer may be necessary, with an assistant to develop the plates, in order that the progress of the eruption may be known and suitable adjustments of the spectroheliograph be made.

Prominence No. 35, observed by the writer at the Yerkes Observatory with the Rumford spectroheliograph, presented an opportunity to obtain detailed information about the eruption over a considerable time. This prominence first appeared on the disk on July 29 as a faint absorption marking in $H\alpha$ on the central meridian. This would put it about one day, 13°, beyond the west limb at the time of the eruption on August 6. On July 30 it had developed strongly, and its thickness measured on the Mount Wilson plates was 8000 km. It then appeared as a hook-shaped marking 140,000 km long, the greater part making a small angle with a solar meridian, the south end bending off toward the west. On July 31 its angular distance from the center of the disk was sufficient to make possible a measurement of the height, which is equal to the measured height divided by the distance of the prominence from the center of the solar disk expressed in terms of the sun's radius. Table V shows the heights of this prominence at intervals during its life.

These measurements were made on the straight part of the prominence at a point where the eruption seemed to take place and, in general, represent the greatest apparent height. There was a steady growth over a period of four or five days, followed by a rapid decay

for two days preceding the eruption. The prominence may be seen on both $H\alpha$ and Ca^+ disk plates, and no special marking can be found in the flocculi within a radius of 30°. The nearest sun-spots were 350,000 km distant and of insignificant dimensions.

The crest of the prominence appeared on the limb on August 3, and during the succeeding three days exposures were made at short intervals. Its form on August 4 strongly suggested eruptive characteristics, but by the following day it had subsided, and on the morning of August 6 it was reduced to half its maximum height. The

TABLE V

HEIGHTS OF THE ERUPTIVE PROMINENCE (NO. 35) OF AUGUST 6, 1931, AT LONG-RANGE INTERVALS THROUGHOUT ITS ENTIRE LIFE

Date G.C.T.	Height in Thousand Kilometers	Date G.C.T.	Height in Thousand Kilometers
July 29.71	Birth	Aug. 5.79	75
31.70	64	6.60	48
Aug. 1.63	67	6.65	64
2.61	92	6.70	114
3.60	103	6.75	342
4.69	100	6.78	620

eruption began on the fourth exposure (six exposures were recorded on each plate during the earlier stages of the eruption), at $15^h07^m.4$, but did not push above the mass of surrounding streamers until $15^h16^m.9$ U.T. A delay of 15 minutes before the next exposure was caused by the development of the first two plates and the call for assistance. After this short break a fairly regular exposure program, at the rate of one exposure each 5 minutes, was kept up until the prominence disappeared 3 hours later. The sky was excellent until the end of the eruption, when clouds intervened for 20 minutes. By the time they had passed, the crest of the prominence had entirely vanished, and only the ropelike stem remained. Throughout most of the eruption this stem appears to have had a spiral structure which had become strongly developed when the stem faded away. Long streamers from the head descended to the base along a curved line nearly parallel to the stem, with velocities of about 125 km/sec. as they neared the chromosphere. Knots in the base of the prominence moved from the brighter part of the stem in streams into the chro-

mosphere at about 40 km/sec. during the last stages of the eruption. This streaming of the prominence into the chromosphere at the same time it is rising is characteristic of an eruption, at least of all those that the writer has witnessed. A considerable part of the fading of the prominence can be accounted for in this way.

During the eruption, drawings of the prominence in $H\alpha$ were made with the spectrohelioscope[1] at Yerkes by Mr. P. C. Keenan, Miss Calvert, and Mr. W. W. Morgan. These are illustrated in Plate VI, together with the corresponding photographs in the H line of Ca^+. A close general correspondence will be noticed. The evidence, therefore, is that in eruptive prominences, also, the hydrogen and calcium are rather thoroughly mixed. In (*f*) the crest and its streamers are entirely missing from the drawings, and in (*g*) only the brighter part of the stem appears. This lack of streamers and fainter clouds, as seen in $H\alpha$, is in keeping with the phenomena of other classes of prominences and is possibly an instrumental effect. Some evidence for this explanation is afforded by the report of Keenan and Morgan that at 18^h40^m the prominence had entirely disappeared in the spectrohelioscope, while the head could be seen on the calcium spectroheliograms faintly and the stem easily as late as 19^h10^m, a half-hour later.

The heights of the crest of this prominence are plotted in Figure 4. Measures of the radial velocity were made at Yerkes and Mount Wilson with spectrohelioscopes of the same construction. At 18^h U.T., Keenan reported, "The broad top of the prominence shows a shift to the red corresponding to about 38 km/sec.," and Morgan states, "There is a slight progressive shift as the distance from the sun increases." Nicholson and Hickox at Mount Wilson found "shifts to the red of 70 to 120 km/sec. at 15^h45^m U.T.," after the eruption had fairly begun and the prominence had an upward velocity of 5 km/sec.

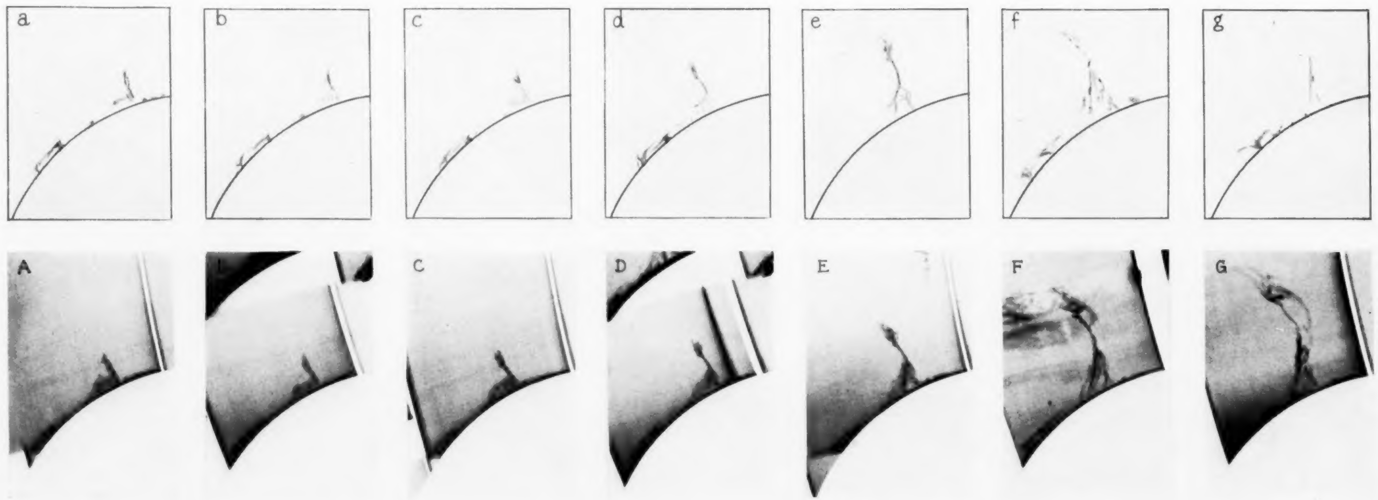
The study of this prominence has involved 209 exposures at the Yerkes Observatory, of which 54 were made during the eruption on August 6; 53 exposures at Mount Wilson, made chiefly while the prominence was on the disk, of which only 2 showed it in the eruptive state; and 14 visual observations of form and velocity made at

[1] *Mt. Wilson Contr.*, No. 388; *Astrophysical Journal*, **70**, 265, 1929.

PLATE VI

Hydrogen
$H\alpha$

Calcium
H



DRAWINGS (a,b,c,d,e,f,g) OF THE ERUPTIVE PROMINENCE OF AUGUST 6, 1931, MADE IN THE $H\alpha$ LINE OF HYDROGEN COMPARED WITH PHOTOGRAPHS (A,B,C,D,E,F,G) MADE IN THE H LINE OF CALCIUM AT THE YERKES OBSERVATORY

(aA) $16^{h}50^{m}.6$; (bB) $17^{h}00^{m}.7$; (cC) $17^{h}13^{m}.0$; (dD) $17^{h}30^{m}.4$; (eE) $17^{h}46^{m}.3$; (fF) $18^{h}05^{m}.7$; (gG) $18^{h}19^{m}.1$.

Drawings (a), (b), (c), (d), and (g) by Keenan; (e) by Morgan; and (f) by Miss Calvert, copied from the spectrohelioscope notebook by Miss Calvert and checked by the other observers before she or they had seen the photographs. The cloudy marking to the left of the head of the prominence in exposure F is a plate defect.

Yerkes and Mount Wilson. Altogether this is perhaps the best-observed prominence so far recorded. An account of the prominence during the active stage will be reserved for a discussion of prominences of class 1.

4. *Measurements of heights by several individuals.*—To test the impartial character of the measurements of the heights of the prom-

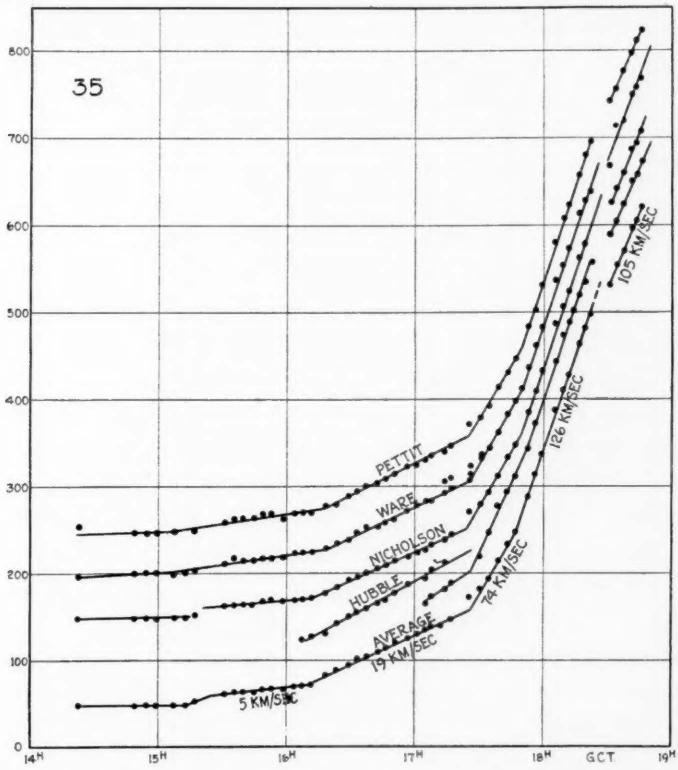


FIG. 4.—Motion of the eruptive prominence (No. 35) of August 6, 1931, as measured on the same plates by different individuals. The scale of ordinates (unit, 1000 km) refers to the "average" plot. The plot of Hubble's measures is raised 50,000 km, Nicholson's 100,000 km, Miss Ware's 150,000 km, and the author's 200,000 km, in order to separate the curves. Abscissae are the times of observation (G.C.T.)

inence of August 6, 1931, the author has asked several of his colleagues to measure the plates independently. The results are presented in Figure 4, where the plots have been separated in ordinate by an amount equal to 50,000 km. The scale to the left corresponds

to the "average" curve. Mr. Hubble's curve is raised 50,000 km; Mr. Nicholson's, 100,000 km, etc. The values in Table IV are the averages of all these measurements. Hubble, experienced in the study of faint nebulosity, has traced the faintest detail visible at the crest which appears to be continuous. Nicholson, Miss Ware, and the author have apparently measured about the same thing, the readily apparent crest. Miss Ware seems to have caught the faint detail seen by Hubble at the break in the curve near 17^h20^m. Hubble's points are all a little higher than those of the other observers. The plot of the averages appears at the bottom of Figure 4. The result must be apparent to everyone, and there can be no escape from the conclusion that the motion was uniform, with three sudden increases in velocity. The decrease in velocity shown by the detached part of the curve is a phenomenon probably connected in many cases with fading, but scarcely in this prominence, as the object measured was a faint knot which became detached from the crest and floated away.

I think it must be granted that in none of the cases presented here, Nos. 30–35, is one warranted in describing the velocities of the prominences as other than uniform. For Nos. 25–30 uniform motion is also generally apparent, except in No. 26, which must be regarded as a doubtful case on account of the scarcity of the observations. If we pick out at random six or seven points along the curve of No. 35 and plot them, the conclusion would probably be the same as that for No. 26.

One is naturally led to inquire as to just what conditions may produce the upward motion of an eruptive prominence. E. A. Milne[1] states that the chromosphere is in any event held up by light-pressure and thereby calculates the average lifetime of an excited calcium atom. That his result is reasonable is an argument that light-pressure is responsible for the existence of the calcium chromosphere. He has suggested[2] that, once the prominence begins its vertical motion, the Doppler shift of the absorption line will expose the atom to the neighboring continuous spectrum and thus introduce an increasing acceleration.

[1] *Monthly Notices of the Royal Astronomical Society*, **84**, 354, 1924.

[2] *Ibid.*, **86**, 474, 1925.

It remains to be shown, however, why this effect would not lead to a separation of the hydrogen and calcium atoms. The prominences disappear as absorption markings on the disk in K spectroheliograms when the slit-width is greater than about 1 A, and do not show strongly unless the slit is set to include only the doubly reversed center of the line, that is, about 0.2 A. The effective width of the H and K absorption lines in the prominences is therefore 0.2 A, while their width in the photospheric spectrum is 10 A. It follows that with increasing velocity of ascent the absorption lines of Ca^+ in prominences will move gradually along the V-shaped absorption lines of the photosphere and reach fully unobstructed photospheric light only when the velocity of the prominence is 385 km/sec.

The $H\alpha$ absorption line has, on the other hand, about the same width, 1 A, in both prominences and photosphere, for the prominences still show faintly as absorption markings when the spectroheliograph slit is set at the extreme edge of the $H\alpha$ line. Hence the $H\alpha$ line of the prominences would be fully exposed to the photospheric light at a velocity of 45 km/sec. At this velocity the absorption line of the Ca^+ atom has moved only about a half-angstrom from the center of the K line in the photosphere, and still has $4\frac{1}{2}$ A to move before reaching the unabsorbed light. The velocity vector of Ca^+ due to light-pressure can therefore be but little disturbed when the $H\alpha$ line has received the full effect.

As already noted, eruptive prominences seem to show no separation of the atoms of neutral hydrogen and ionized calcium, and it therefore still remains to be shown that such an effect exists, if light-pressure is to be accepted as an explanation of the motions of eruptive prominences.

Pike,[1] starting with Milne's theory, discusses the effect of bright neighboring areas on the prominences already in equilibrium with radiation pressure and finds[2] that facular areas of the order 200,000 km square radiating in the region of H and K at an effective temperature of 7500° K would produce the average observed velocities of eruptive prominences. R. K. Sur[3] has made calculations on the same lines. W. H. McCrea[4] discusses the physical theory of light-

[1] *Ibid.*, **88**, 3, 1927. [2] *Ibid.*, p. 22, 1927. [3] *Astrophysical Journal*, **63**, 111, 1926.
[4] *Monthly Notices of the Royal Astronomical Society*, **89**, 483, 1928.

pressure on excited atoms of hydrogen in the chromosphere and finds that radiation pressure can support only about one-tenth the gravitational pull of the sun, and later[1] introduces the idea of turbulence to account for the remainder. N. T. Bobrovnikoff[2] has computed the central force necessary to produce the observed motions in eruptive prominences whereby arcs of parabolas were made to approximate the observed straight lines of the motion diagrams.

In all these theoretical considerations a continuously accelerated motion is postulated, which is in contradiction to the principle of uniform motion found in these investigations. It would seem that any adequate explanation must account for the observed motions.

TABLE VI

L	B^2	R	Vol. $= LB^2$	$2R^6$
13	9	94	117	138
12	36	114	432	438
15	49	123	735	692
20	64	134	1280	1162

Our inability to understand how prominences can have uniform motion of ascent may be due, in part at least, to a neglect of the presence of the corona through which it moves. It is well known that bodies of gas lighter than air inclosed in rubber balloons ascend in our own atmosphere with uniform motion,[3] the expansion of the gas keeping pace with the decreasing density of the atmosphere—this in spite of the constant accelerative force of levitation. That an analogous condition exists in prominences is suggested by the following argument.

If we suppose that the head of prominence No. 35 expanded in the line of sight at the same rate as in the other two dimensions, we can determine its volume for any moment in arbitrary units by multiplying the length L of the head by the square of its breadth B. The results are shown in Table VI. Here the dimensions of the prominence are in units of which the solar radius $R=89$.

A comparison of the last two columns of Table VI indicates that

[1] *Ibid.*, p. 718, 1928. [2] *Astrophysical Journal*, **74**, 157, 1931.

[3] Sir N. Shaw, *Manual of Meteorology*, **1**, 222, 1926.

the volume of the prominence appears to vary nearly as the sixth power of the distance from the center of the sun, and that the inverse relation would hold for the density d, namely, $d \approx R^{-6}$.

Let us compare the variation in density of the prominence with that of the corona.

THE CORONAL DENSITY GRADIENT

We know that the apparent visual intensity of the corona[1] varies inversely with the seventh power of the distance from the center of

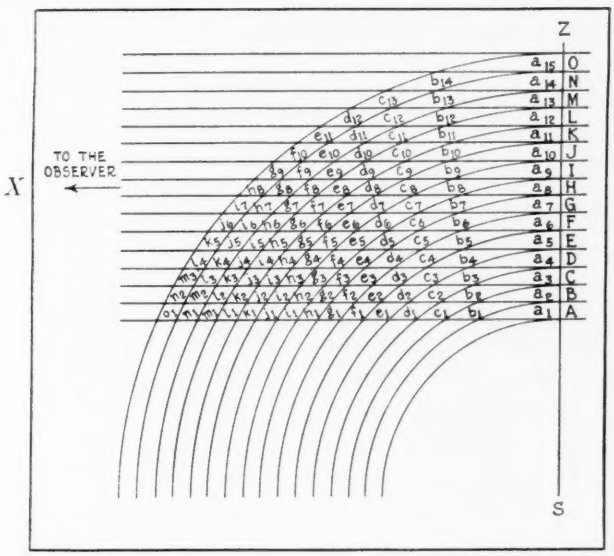


FIG. 5

the sun. To obtain from this an expression of density, let us first determine the actual variation of intensity of the light in a unit volume (the volumetric brightness) of concentric shells of equal width in the corona. It will be necessary to assume that the intensity in these shells varies according to various powers of R until one is found that yields a computed apparent coronal intensity which varies inversely with the seventh power of R.

Let Figure 5 represent a cross-section of the concentric shells in the plane of the observer (in the direction X), each shell of the thickness 0.1 radius of the sun. Since the figure is symmetrical about the

[1] *Mt. Wilson Contr.*, No. 290; *Astrophysical Journal*, **62**, 202, 1925.

line SZ, we shall need to consider only that part of the corona to the left of this line. The intensity of the light directed to the observer by a shell of the corona is represented by that included in the equal tubes indicated by the spaces between the horizontal lines. The light contributed by each shell to any tube is given by the volume of the shell cut out by the tube (length may be used as a measure of volume), multiplied by the volumetric brightness of the shell (or zone). If we represent the volumetric brightness of each shell by A, B, C, ..., etc., and the corresponding volumes of the portions of the shells intercepted by the tubes by $a_1, b_1, c_1, \ldots, a_2, b_2, c_2, \ldots,$ $a_3, b_3, c_3, \ldots,$ etc., the total light L_1, L_2, L_3, etc. entering the first, second, and third tubes in the direction of the observer is given by

$$L_1 = Aa_1 + Bb_1 + Cc_1 \; , \; . \; . \; . \; . \; , \text{ etc.,}$$

$$L_2 = Ba_2 + Cb_2 + Dc_2 \; , \; . \; . \; . \; . \; , \text{ etc.,}$$

$$L_3 = Ca_3 + Db_3 + Ec_3 \; , \; . \; . \; . \; . \; , \text{ etc., etc.,}$$

and the sequence can be extended to any shell. The results of the summations for values of A, B, C, etc., depending on the volumetric brightness $\overline{B}$ varying according to R^{-7} and R^{-8} are given in Table VII.

The quantities in the fourth and fifth columns have been multiplied by factors which make the figures directly comparable with those in the third column. It will be noted at once that the third and fourth columns agree very well, while the third and fifth do not. It follows, then, that if the apparent brightness of the corona varies inversely with the seventh power of the distance from the center of the sun, the real intensity or volumetric brightness of the contributing shells varies inversely with the eighth power of their radii. This result is a little surprising since one would expect the greater optical path toward the limb of the sun to make the apparent brightness greater than the real. This, however, is counterbalanced by the very steep intensity gradient toward the limb.

If we assume that the coronal particles shine by reflected light, their intrinsic brightness will vary inversely with the square of R, making the outer corona too faint. Since we have found that the brightness actually varies inversely as the eighth power of R, it fol-

lows that if the particles were equally illuminated, the volumetric brightness of the corona would vary inversely with the sixth power of R, and therefore the actual density follows the same law, viz., $d \precsim R^{-6}$.

We have already seen in Table VI that the density of the prominence of August 6, 1931, follows the law $d \precsim R^{-6}$, and we may conclude that we have here a volume of gas that expands as it rises, keeping its density about in step with that of the corona.

TABLE VII

Shell No.	R	R^{-7}	L When $\bar{B} \simeq R^{-8}$	L When $\bar{B} \simeq R^{-7}$
1	1.05	0.714	0.679	0.500
2	1.15	.370	.381	.305
3	1.25	.208	.204	.176
4	1.35	.122	.123	.113
5	1.45	.074	.081	.078
6	1.55	.056	.052	.052
7	1.65	.030	.032	.034
8	1.75	.020	.020	.021
9	1.85	.014	.014	.015
10	1.95	.009	.009	.010
11	2.05	.007	.006	.007
12	2.15	.005	.004	.005
13	2.25	.003	.003	.004
14	2.35	.002	.003	.003
15	2.45	0.002	0.001	0.001

It is difficult to find any explanation for the sudden increases in velocity. The corona is about as non-homogeneous as possible, being made up almost entirely of streamers radiating from the sun in curved lines. Perhaps these streamers carry high-speed electrons which, passing through the prominence, give it the necessary impulse. As yet all this is speculative, for we know nothing of the actual working of this phenomenon, although its presence in terrestrial magnetic storms is fairly well established.

Another feature of eruptive prominences which finds its analogue in terrestrial meteorology is their tendency to become spiral. Number 35 showed this feature in the narrow stem in the later phases of the erution. That of May 29, 1919, exhibited it on a gigantic scale in the last stages, when the whole prominence formed a spiral ribbon. In fact, all the eruptive prominences I have examined, with

the exception of No. 3, showed this tendency, particularly in the later stages of the eruption.

TORNADO PROMINENCES (CLASS 4)

The spiral form in a prominence sometimes gives it the appearance of a closely wound rope or screw. Plate II, class 4, shows an example photographed at intervals of about seven minutes. The phenomena remind us of the small desert dust storms which appear as whirling columns, the angular velocity finally becoming so high that the vortex explodes, as shown in the case of the prominence, by the third exposure. These objects are relatively small and require good atmospheric definition to show the spiral structure. Seventeen cases with three available exposures each were found among the photographs taken with the 13-foot spectroheliograph at Mount Wilson during the last sun-spot cycle. They average 12,000 km in diameter and 53,000 km in height, but vary from 5600 to 22,000 km in diameter and from 25,000 to 97,000 km in height. In every case a faint, diffuse, smokelike column issues from the top of the vortex, often bent over and, in some cases, touching the chromosphere.

In no case is any lateral motion of the whole spiral toward the north or south detectable, although in two cases the time interval between the first and third exposures was 1^h45^m and 2^h30^m, respectively. The customary interval was 12–24 minutes. Unfortunately, we have no direct method of detecting these objects on the disk unless it be from a spiral form in the surrounding flocculi, and we therefore do not know whether there is any proper motion in longitude.

QUIESCENT PROMINENCES (CLASS 5)

An example of class 5 is illustrated in Plate II. This prominence was photographed at the Yerkes Observatory on August 21, 1930. In all, 55 exposures were made between 14^h20^m and 19^h40^m U.T., most of the series being at intervals of 5 minutes. The plates were measured by Miss Ware with the blink comparator. Figure 6, a plot of the observed vectors, shows that the prominence is in a state of turbulence. Velocities of 5–10 km/sec. are common, but 15 km/sec. is rare. The form changed only slightly during the day, the three exposures in Plate II made by Hickox at Mount Wilson showing it

at a time of maximum change. It thus seems that the quiescent state is simply one in which the rate at which the prominence receives material from the chromosphere is the same as that at which

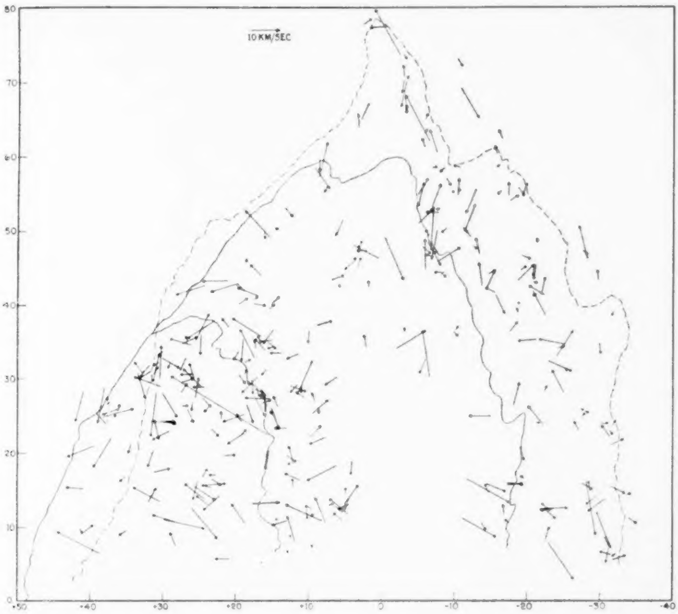


FIG. 6.—Internal motions of the quiescent prominence of August 21, 1930, during the interval 14^h20^m to 19^h40^m G.C.T. The co-ordinates are in units of 1000 km. The dotted line shows the outline at the end of observation.

it returns it. Additional data concerning this class and classes 1 and 3 will be reserved for a future discussion.

My thanks are due to Professor Frost for the use of the Rumford spectroheliograph at the Yerkes Observatory; to Mr. Keenan and Mrs. Pettit for assistance; to Mr. Hickox and Mr. Nicholson for assistance at Mount Wilson; and to Miss Ware and Miss Richmond for aid in the measurement and reduction of the observational material.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
January 1932

NEBULOUS OBJECTS IN MESSIER 31 PROVISIONALLY IDENTIFIED AS GLOBULAR CLUSTERS[1]

By EDWIN HUBBLE

ABSTRACT

One hundred and forty nebulous objects have been found in or close to the borders of Messier 31 which, from their numbers, their distribution, and the radial velocity of a typical example, are presumably associated with the spiral. From their forms, structure, colors, luminosities, and dimensions they are *provisionally identified as globular clusters.*

Absolute photographic magnitudes range from -4 to -7, the mean being -5.3. The luminosity function has a double maximum, which suggests a mixture of two homogeneous groups having most frequent magnitudes at -5.0 and -6.2. *Diameters range* from about 4 to 16 parsecs.

The *number of objects* per unit area *decreases* with distance from the nucleus of M 31, and occasional objects are found as far as $3\overset{\circ}{.}5$ from the nucleus. The *diameter of the spiral* as derived from the distribution of these objects is probably of the order of 30,000 parsecs.

According to Shapley's distances and magnitudes for the clusters in our system, reduced to the conventional scale, *the objects in M 31 are systematically fainter* than the galactic globular clusters, by an amount varying from about 0.75 to 1.95 mag. according to the interpretation of the data. The ranges in absolute luminosity are of the same order, however, and the two groups overlap to a considerable extent.

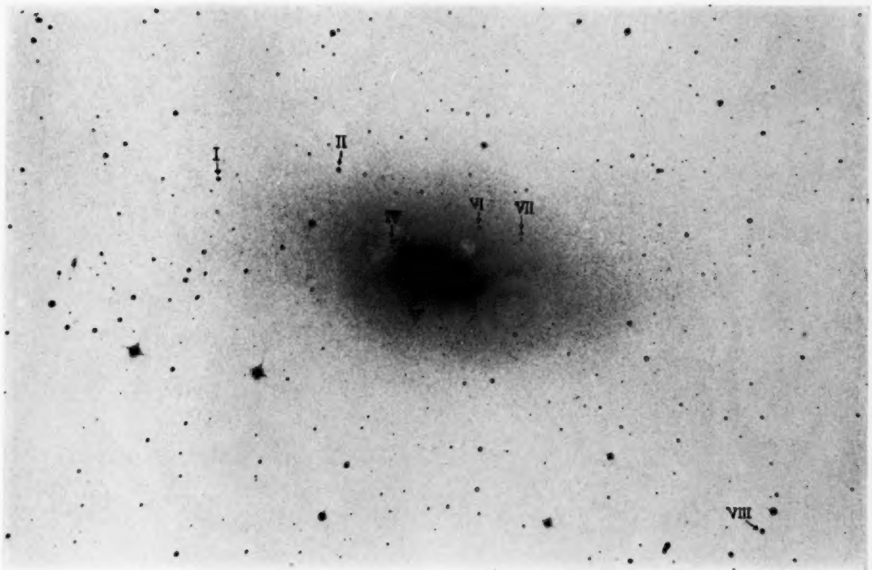
The *known globular clusters* in the Magellanic Clouds *are comparable* with the brighter objects in M 31. *Objects* apparently *similar* to those in M 31 *are found* in N.G.C. 6822, M 33, M 81, and M 101.

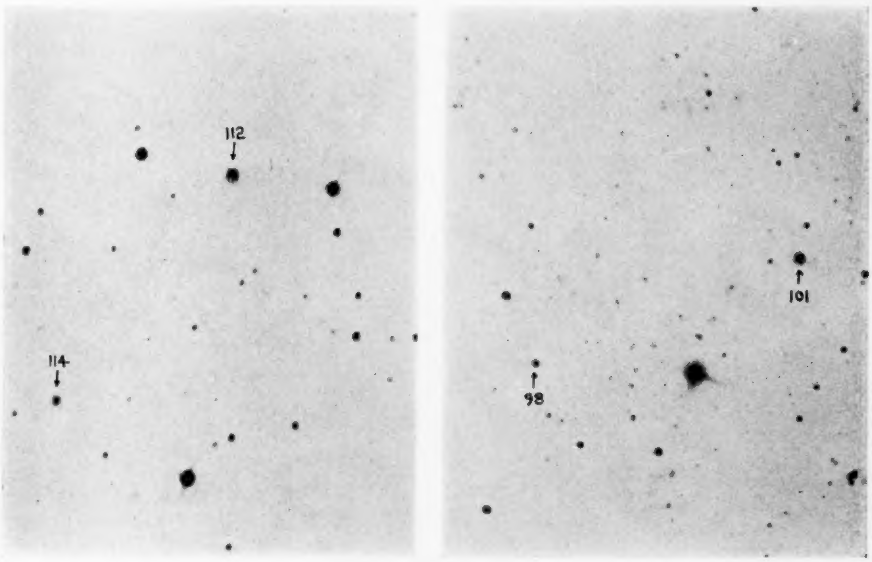
The great spiral in Andromeda, Messier 31, lies in a region of the sky where the distribution of extra-galactic nebulae appears to be normal. Within the limits of M 31 the typical small nebulae are not numerous; in fact, they can be identified with reasonable certainty only in the outermost parts. Over the face of the spiral, however, are found many nebulous objects that approximate to the general appearance of extra-galactic nebulae but can be distinguished from the latter with some confidence on large-scale plates where the images are sharply defined.

The objects in question may be described as "nebulous stars." They are small, highly concentrated, round, and perfectly symmetrical. On the plates they resemble soft, hazy star images, but build up with increasing exposure in a manner perceptibly different from true stellar images. Visually they appear like small condensed nebulae. In the case of the brighter objects, the nebulous character is

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington,* No. 452.

PLATE VII

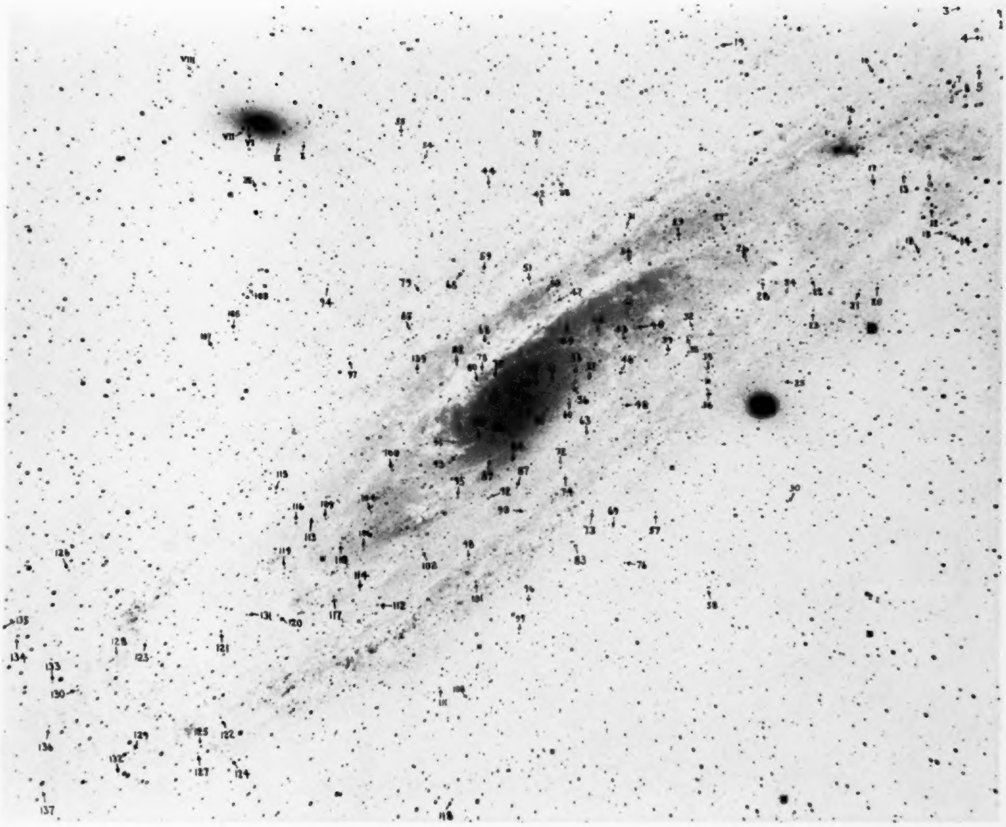




(Above) N.G.C. 205, 100-inch reflector. North is to the right. Scale, 1 mm = 8″.9. Object No. III is out of the field but is marked on Plate VIII.

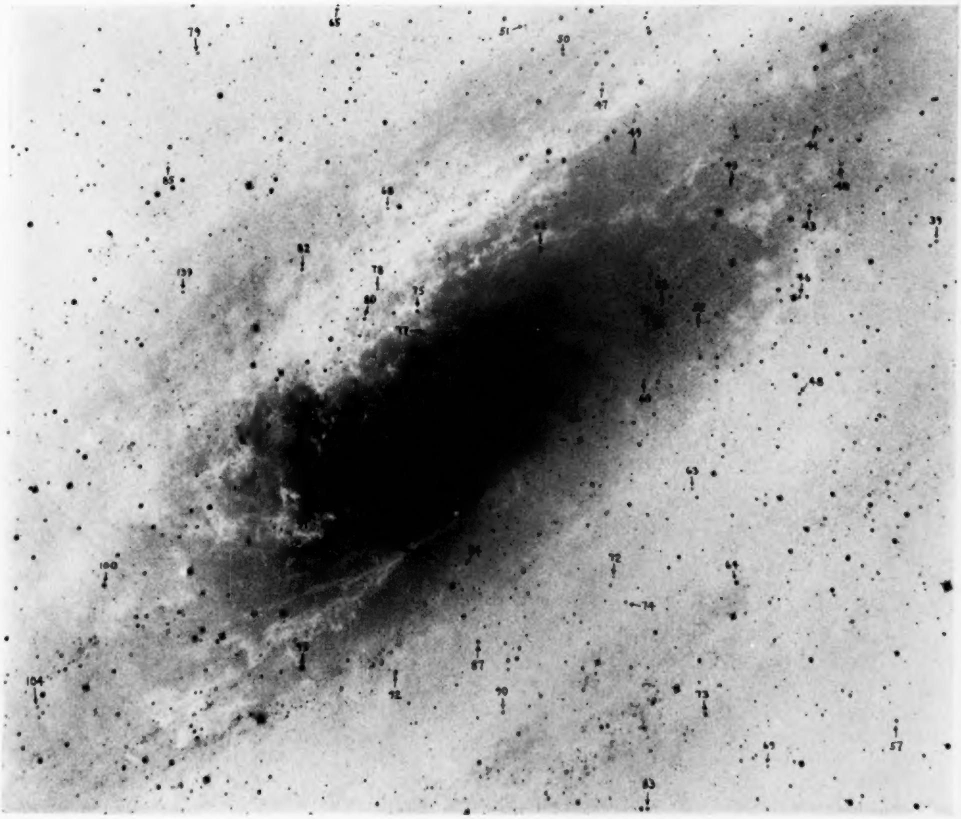
(Below) Typical objects with 100-inch reflector. South is at the top. Scale, 1 mm = 3″.7. Objects Nos. 101 and 112 represent the extreme range in degree of condensation.

PLATE VIII



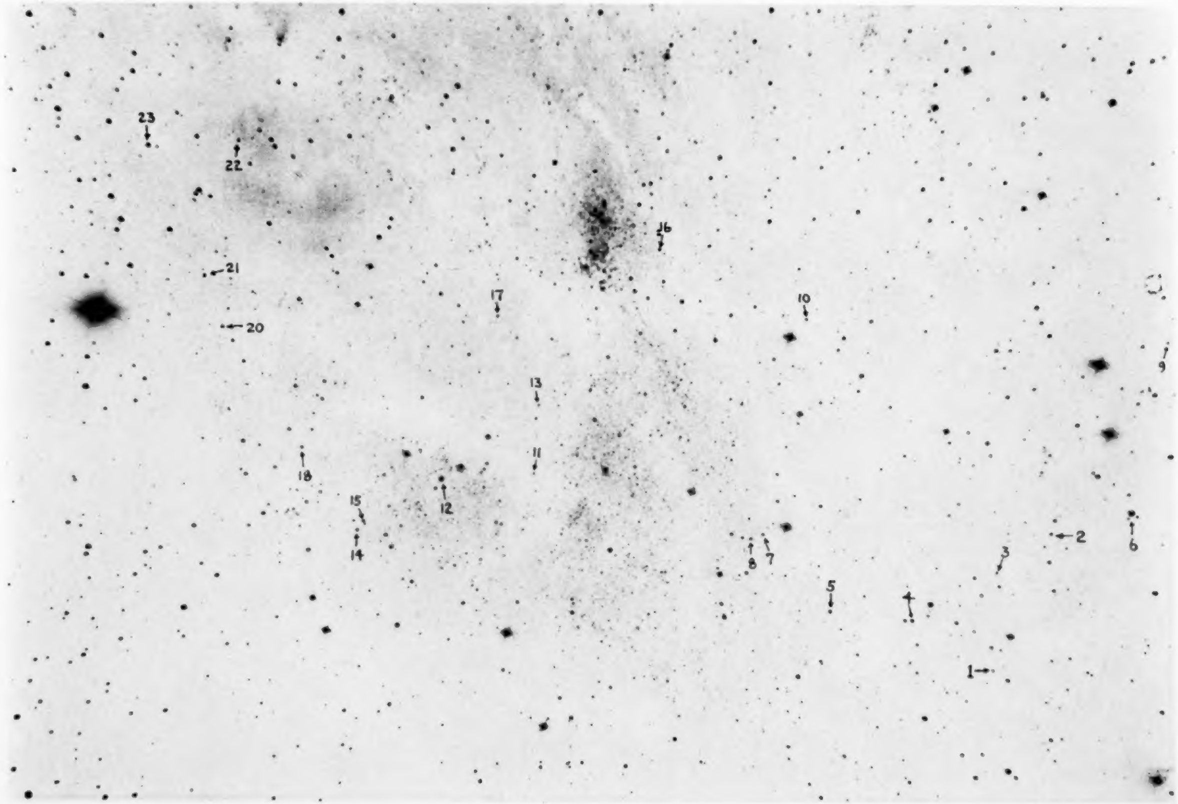
Messier 31 with the 24-inch Yerkes reflector. North is to the left. Scale, 1 mm = 44″. Objects Nos. 2, 6, and 9 are out of the field but are marked on Plate X. Objects Nos. IV and V, near the nucleus of N.G.C. 205, are omitted, but are marked on Plate VII. Objects Nos. 138, 139, and 140 are out of the fields of all plates. Their positions are indicated by the co-ordinates in Table I.

PLATE IX



Central region of Messier 31 with 100-inch reflector. North is to the left. Scale, 1 mm = 14″.7

PLATE X



Outer region of Messier 31, centered about 45′ south preceding the nucleus, with the 100-inch reflector. North is at the top. Scale, 1 mm = 15″.8.

more conspicuous in the telescope than on the photographic plate. Mr. M. L. Humason, who has examined several of the objects at the 135-foot focus of the 100-inch reflector, confirms this description and adds that the objects are appreciably more colored (larger color-index) than certain small clusters of early-type stars that are known in the spiral.

The general features of the photographic images are indicated by typical examples shown in Plate VII. Their appearance approximates that of the most condensed of the globular nebulae, a type rarely found; but their numbers and their symmetrical distribution suggest that the objects are associated with the great spiral itself. This relationship is confirmed, even established, by a spectrogram of a typical example, No. 62 in Table I, obtained by Mr. Humason with a small-scale spectrograph on the 100-inch reflector. The spectral type is estimated as about F8 and the radial velocity as about -210 km/sec., with an uncertainty of the order of 100 km/sec. Within the uncertainties of the measures the object shares the unique velocity of M 31 and hence an actual association is presumed.

The observed characteristics of the objects appear to admit of but one interpretation. On the basis of structure, luminosity, diameters, and colors, the objects are provisionally identified as globular clusters. Their absolute magnitudes are systematically fainter by one or two magnitudes than the absolute magnitudes of the globular clusters in the galactic system derived from Shapley's distances; but the range in absolute luminosity for the two groups of objects is much the same, and there is a considerable overlap in luminosity.

OBSERVATIONAL DATA

The objects in M 31 are marked for identification on Plates VIII, IX, and X and are listed in Table I together with their positions, photographic magnitudes, diameters in seconds of arc, and rough indications of the degree of concentration. Positions are given in minutes of arc from the nucleus of M 31, X along the major axis (+ to the south preceding), Y along the minor axis (+ to the north preceding). The orientation of the major axis is assumed to be N. 36°7 E. in accordance with a previous determination.[1] The fourth

[1] *Mt. Wilson Contr.*, No. 365; *Astrophysical Journal*, **69**, 103, 1929.

TABLE I

NEBULOUS OBJECTS IN MESSIER 31

	X	Y	4Y	D	m(pg)	d	Conc.
1	+60'.6	+ 3'.4	13'.6	62'.1	17.4	6	m
2	58.0	+ 7.8	31.2	65.9	17.1	6	c
3	57.9	+ 5.6	22.4	62.1	17.2	5	m
4	57.7	+ 2.2	8.8	58.4	16.2	6	c
5	55.7	+ 0.1	0.4	55.7	16.7	6	m
6	59.1	+10.4	41.6	72.3	17.4	5	m
7	52.2	− 0.2	0.8	52.2	17.0	6	m
8	52.0	− 0.6	2.4	52.1	17.2	5	m
9	54.7	+15.0	60.0	81.2	16.8	5	m
10	47.0	+ 5.3	21.2	51.6	17.1	6	d
11	45.8	− 5.4	21.6	50.7	18.0	5	m
12	44.1	− 8.1	32.4	54.7	15.0	10	m
13	44.0	− 3.9	15.6	46.7	18.0	5	m
14	43.8	−11.5	46.0	63.5	17.3	7	d
15	43.6	−11.1	44.4	62.2	17.2	5	m
16	42.1	+ 2.6	10.4	43.4	16.1	6	c
17	40.7	− 3.3	13.2	42.8	17.2	5	c
18	40.4	−11.4	45.6	60.9	17.2	7	m
19	36.2	+16.5	66.0	75.3	16.0	6	c
20	35.5	−11.3	45.2	57.5	17.0	5	c
21	33.7	−10.7	42.8	54.5	17.0	5	c
22	30.6	− 7.0	28.0	41.5	17.3	7	d
23	28.9	− 9.7	38.8	48.4	15.5	10	c
24	27.5	− 6.8	27.2	38.7	17.9	4	m
25	22.6	−13.3	53.2	57.8	18.2	4	m
26	26.5	− 1.8	7.2	27.5	16.2	7	m
27	26.4	+ 1.5	6.0	27.1	16.3	7	m
28	26.5	− 5.7	22.8	35.0	18.2	4	m
29	22.4	+ 3.4	13.6	26.2	17.4	4	m
30	16.2	−23.1	92.4	93.8	16.8	5	m
31	18.9	+ 7.6	30.4	35.8	17.8	4	d
32	18.5	− 4.1	16.4	24.7	16.8	6	m
33	17.6	− 4.4	17.6	24.0	16.5	5	m
34	17.2	+ 4.5	18.0	24.9	16.8	5	m
35	17.2	− 8.3	33.2	37.4	16.1	6	m
36	16.4	− 9.8	39.2	42.5	16.5	6	m
37	16.5	+19.0	76.0	77.8	17.1	5	m
38	16.4	+15.1	60.4	62.6	16.7	5	c
39	15.2	− 4.6	18.4	23.9	16.8	6	m
40	+14.1	− 0.8	3.2	14.4	17.1	5	m

TABLE I—*Continued*

	X	Y	4Y	D	m(pg)	d	Conc.
41	+14′.1	+ 0′.6	2′.4	14′.3	16.7	5	c
42	13.6	+14.2	56.8	58.4	15.3	8	m
43	12.5	− 1.3	5.2	13.5	17.1	5	m
44	10.4	+18.5	74.0	74.7	15.5	9	c
45	10.8	+ 0.8	3.2	11.3	16.8	4	c
46	10.6	− 3.5	14.0	17.6	16.8	5	m
47	9.3	+ 5.8	23.2	25.0	17.5	4	m
48	8.8	− 6.0	24.0	25.6	16.9	6	m
49	8.9	+ 3.4	13.6	16.3	16.3	5	c
50	8.8	+ 7.3	29.2	30.5	16.8	5	m
51	8.3	+ 8.7	34.8	35.8	18.0	4	m
52	7.4	− 2.4	9.6	12.1	17.5	5	m
53	6.8	− 1.1	4.4	8.1	16.9	4	m
54	6.8	+24.6	98.4	98.6	17.6	3	m
55	6.5	+27.6	110.4	110.5	16.3	7	m
56	6.0	− 1.5	6.0	8.5	16.6	5	m
57	5.4	−16.3	65.2	65.4	16.3	6	m
58	5.1	−25.2	100.8	100.9	17.0	7	m
59	5.2	+12.2	48.8	49.1	16.8	5	c
60	4.9	− 2.8	11.2	12.2	17.1	4	m
61	4.6	− 0.2	0.8	4.7	16.6	5	c
62	4.7	+ 2.6	10.4	10.5	15.4	8	m
63	4.2	− 6.5	26.0	26.3	17.5	5	m
64	3.7	− 9.7	38.8	39.0	15.2	8	c
65	3.8	+12.8	51.2	51.3	16.9	5	m
66	2.9	− 1.9	7.6	8.1	17.0	4	c
67	2.8	+ 0.2	0.8	2.9	16.5	4	c
68	1.3	+ 6.6	26.4	26.4	17.4	4	m
69	1.1	−15.1	60.4	60.4	17.2	5	m
70	1.2	− 0.9	3.6	3.8	15.0	8	c
71	0.9	− 2.3	9.2	9.2	16.8	3	c
72	0.6	− 7.3	29.2	29.2	17.0	4	m
73	0.5	−12.6	50.4	50.4	15.9	6	c
74	0.4	− 8.2	32.8	32.8	16.6	6	m
75	0.2	+ 3.3	13.2	13.2	15.6	6	c
76	+ 0.1	−18.5	74.0	74.0	15.8	7	c
77	0.0	+ 2.6	10.4	10.4	16.6	4	c
78	− 0.4	+ 4.6	18.4	18.4	17.0	4	m
79	− 0.8	+14.2	56.8	56.8	16.9	4	m
80	− 1.3	+ 4.1	16.4	16.5	16.0	5	c

TABLE I—*Continued*

	X	Y	4Y	D	m(pg)	d	Conc.
81	−1′.5	− 0′.4	1′.6	2′.2	15.5	4	c
82	2.0	+ 6.6	26.4	26.5	17.0	6	m
83	2.7	−14.0	56.0	56.1	16.8	6	d
84	3.1	− 4.2	16.8	17.1	17.0	5	m
85	3.6	+11.9	47.6	47.7	17.6	5	m
86	3.7	− 1.8	7.2	8.1	15.9	5	c
87	4.2	− 6.5	26.0	26.3	15.8	7	m
88	4.2	− 0.4	1.6	4.5	16.5	5	c
89	4.5	− 2.6	10.4	11.3	16.0	5	c
90	4.8	− 8.8	35.2	35.5	15.7	6	c
91	6.3	+ 0.3	1.2	6.4	15.8	6	c
92	6.9	− 5.8	23.2	24.2	15.7	7	c
93	7.1	− 0.6	2.4	7.5	15.4	8	c
94	7.7	+20.2	80.8	81.2	16.3	7	m
95	9.3	− 3.8	15.2	17.8	15.3	8	m
96	9.8	−16.3	65.2	65.9	17.3	4	m
97	10.2	+13.2	52.8	53.8	16.1	8	m
98	11.9	− 9.4	37.6	39.4	16.6	6	c
99	12.2	−18.0	72.0	73.0	15.8	6	c
100	13.0	+ 2.0	8.0	15.3	15.7	7	c
101	12.6	−11.6	46.4	48.1	15.2	7	c
102	15.1	− 6.0	24.	28.4	15.8	7	c
103	14.1	+24.4	97.6	98.6	17.1	5	m
104	17.0	+ 0.1	.4	17.0	17.1	4	m
105	17.7	+21.8	87.2	89.0	16.8	6	c
106	19.7	− 2.6	10.4	22.3	15.7	7	c
107	20.3	+21.8	87.2	89.5	17.3	6	m
108	19.7	−20.4	81.6	83.9	16.8	6	m
109	20.9	+ 2.0	8.0	22.4	17.0	4	m
110	21.1	− 0.8	3.2	21.3	17.0	4	m
111	21.4	−17.7	70.8	74.0	17.1	5	m
112	21.6	− 7.7	30.8	38.1	15.7	10	d
113	21.8	+ 2.9	11.6	24.7	17.3	4	m
114	22.2	− 5.5	22.0	31.3	17.0	6	m
115	23.4	+ 6.8	27.2	35.9	15.9	7	c
116	23.5	+ 3.3	13.2	26.9	16.0	6	c
117	24.7	− 4.6	18.4	30.8	17.0	5	m
118	26.7	−27.2	108.8	112.0	16.0	6	c
119	26.8	+ 0.4	1.6	26.8	17.0	5	m
120	−30.1	− 2.9	11.6	32.3	17.1	8	d

TABLE I—*Continued*

	X	Y	4Y	D	m(pg)	d	Conc.
121	−35.4	− 0′.9	3′.6	35′.6	16.1	6	c
122	40.3	− 7.7	30.8	50.7	18.0	4	m
123	41.8	+ 2.6	10.4	43.1	17.4	4	c
124	41.8	−11.5	46.0	62.2	17.7	4	c
125	43.4	− 8.8	35.2	55.9	15.8	5	c
126	43.9	+12.9	51.6	67.7	17.5	4	m
127	44.1	− 9.1	36.4	57.2	17.7	5	m
128	45.0	+ 3.2	12.8	46.8	17.7	5	m
129	48.8	− 5.3	21.2	53.2	17.0	4	c
130	50.0	+ 2.7	10.8	51.2	16.3	5	c
131	32.4	− 1.0	4.0	32.6	17.0	5	m
132	51.5	− 6.2	24.8	57.2	17.3	4	c
133	51.6	+ 4.8	19.2	55.1	17.2	5	c
134	52.0	+10.5	42.0	66.8	16.2	7	m
135	53.3	+11.5	46.0	70.4	17.5	5	c
136	54.3	+ 1.5	6.0	54.6	16.9	5	m
137	58.4	− 3.0	12.0	59.6	17.0	6	m
138	59.7	−14.9	59.6	84.4	17.0	6	d
139	5.6	+ 8.2	32.8	33.3	17.2	5	m
140	−62.4	−51.0	204.0	213.3	15.5	7	c

column of Table I gives the *Y* co-ordinates quadrupled in order to correct for the tilt of the spiral, and the fifth column the distance from the nucleus as determined from the measured *X* and the corrected *Y*.

Photographic magnitudes for the objects brighter than about 17.2 were derived from extra-focal exposures, with the exception of several near the nucleus of M 31 and a few in the extreme north following end. Magnitudes for these exceptions and for the objects fainter than 17.2 were estimated on focal exposures, but closely conform to the scale established by the extra-focal measures. The magnitudes near the nucleus are slightly uncertain, since exposures of one minute or less were required to register the objects free from a luminous background, and the comparison with more distant objects assumes that the building-up of the images with increasing exposure is the same in both cases. With the exception of No. 12, 55′ S. preceding the nucleus, No. 70, the object nearest the nucleus, is also the brightest of the list.

Diameters on hour exposures with fast plates range from about

10″ to 4″ as the magnitudes range from about 15.0 to 18.0; but these are minimum values, since the images were measured against a luminous background. Experience indicates that the background diminishes the apparent diameters, an effect previously observed[1] in the growth of the image of M 32, the brighter companion of M 31, and shown by the present data in the systematic increase in the sum $m+5 \log d$ with increasing distance from the nucleus.

The objects are all very similar and differ only in the degree of concentration toward the center. The luminosity fades from the center outward to undefined edges, and the rate of fading, i.e., the degree of concentration, ranges from that exhibited in No. 101 to that in No. 112 (see Pl. VII). The objects are roughly classed in three groups as "c," highly concentrated; "m," moderately concentrated; and "d," diffuse. The range is perhaps comparable to that exhibited by the globular clusters in the galactic system.

DISTRIBUTION OVER THE SPIRAL

Of the 140 objects listed in Table I, 130 are within the recognized boundaries of the spiral, 9 are in the immediate vicinity, and 1, a typical example, is well beyond the borders. Only 2 are fainter than magnitude 18.0. The list is believed to be reasonably complete, except for the extreme tips of the spiral, where few would be expected even if plates of the necessary quality were available. The nature of the very faint objects is somewhat uncertain, and further investigation may slightly revise the data for objects fainter than say 17.5.

The large number of objects within the borders of the spiral contrasts sharply with the number of extra-galactic nebulae to be expected on the basis of the normal distribution observed in the general vicinity. The normal distribution is represented by the equation[2]

$$\log N = 0.6\,m - 9.5 ,$$

where N is the number per square degree to the limiting photographic magnitude m. Since the spiral covers an area of the order of 1.4 square degrees (an ellipse about $160' \times 40'$), some twenty-eight

[1] *Mt. Wilson Contr.*, No. 398; *Astrophysical Journal*, **71**, 231, 1930.

[2] *Science*, **75**, 25, 1931.

nebulae may be expected to the limit 18.0. They should be distributed about as follows:

<15.5	1
15.5–16.0	1
16.0–16.5	2
16.5–17.0	4
17.0–17.5	7
17.5–18.0	14

Deviation from normal distribution might materially alter the numbers, but, in view of the relative infrequency of highly concentrated globular forms among nebulae in general, it seems improbable that any considerable number of extra-galactic nebulae are included in Table I. For the same reason it is also improbable that the objects represent a cluster of nebulae projected on the spiral.

The distribution of the objects with respect to the nucleus of M 31 is indicated in Figure 1. The co-ordinates of the points are the values of X and $4Y$ listed in Table I; hence the distribution is that seen in a direction perpendicular to the plane of the spiral. The method of presentation neglects the scatter of the objects above and below the equatorial plane, but the uncertainty from this source should not seriously affect the general nature of the conclusions concerning the distribution. The brighter objects, magnitude 16.5 and brighter, are distinguished from the fainter in order to indicate separately the distribution of the two groups. The frequency distribution of magnitudes, as will appear later, suggests that the division may have some significance.

The distribution is roughly symmetrical about the nucleus, although the counts indicate an appreciable excess in the number of objects with negative Y over that for objects with positive Y. The same feature is exhibited in the distribution of novae and variable stars in M 31,[1] and hence both the general distribution and the minor dissymmetry indicate an association of the objects with the spiral.[2]

[1] *Mt. Wilson Contr.*, No. 376; *Astrophysical Journal*, **69**, 103, 1929.

[2] Attempts have been made to account for the dissymmetry by various patterns of obscuration, but the procedure is arbitrary and the conclusions are uncertain. For instance, if we assume complete obscuration beyond the equatorial plane and ellipsoidal distribution of the objects, the observed distribution then indicates that the north-

The data are summarized in Tables II and III, which list the numbers of objects observed in successive zones concentric with the nu-

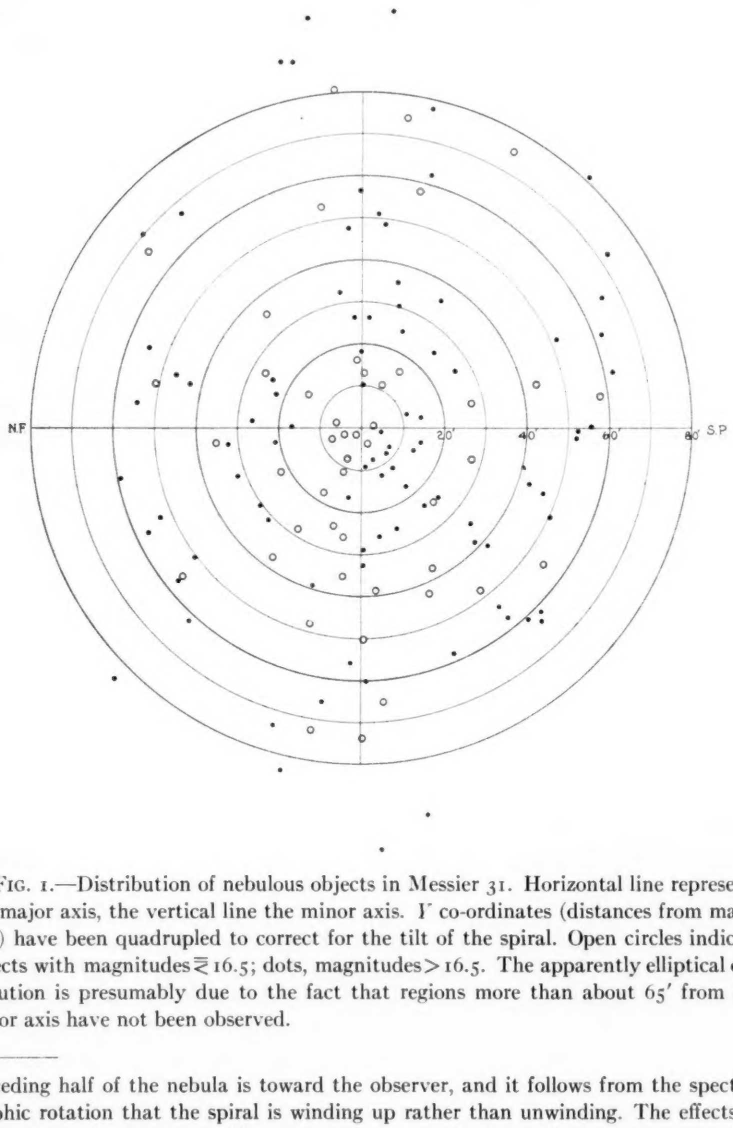


FIG. 1.—Distribution of nebulous objects in Messier 31. Horizontal line represents the major axis, the vertical line the minor axis. Y co-ordinates (distances from major axis) have been quadrupled to correct for the tilt of the spiral. Open circles indicate objects with magnitudes $\leqq$ 16.5; dots, magnitudes > 16.5. The apparently elliptical distribution is presumably due to the fact that regions more than about 65′ from the minor axis have not been observed.

---

preceding half of the nebula is toward the observer, and it follows from the spectrographic rotation that the spiral is winding up rather than unwinding. The effects of obscuration both in M 31 and in our own system are obviously of great importance, but adequate discussion must be based on a wide range of data, much of which is as yet unorganized.

cleus of M 31, together with the numbers per unit area, and the mean distances from the nucleus, the magnitudes, the logarithms of the diameters, and the sums $m+5 \log d$ for the objects in each zone. In

TABLE II

DISTRIBUTION OF NEBULOUS OBJECTS WITH RESPECT TO NUCLEUS OF MESSIER 31
(5′ Zones)

Zone	Numbers B	Numbers F	Numbers All	Area of Zone	Density N/Area	$\bar{D}$	$\bar{m}(pg)$	$\overline{\log d}$	$m+5 \log d$
0′– 5′	4	1	5	1	5.0	3.6	16.02	0.701	19.52
5 –10	3	4	7	3	2.33	8.0	16.34	.680	19.74
10 –15	3	7	10	5	2.00	12.3	16.59	.698	20.08
15 –20	4	4	8	7	1.14	17.0	16.40	.718	19.99
20 –25	3	6	9	9	1.00	23.6	16.62	.717	20.20
25 –30	5	8	13	11	1.17	26.8	16.75	.732	20.41
30 –35	1	7	8	13	0.62	32.3	17.11	.732	20.77
35 –40	6	4	10	15	0.67	37.1	16.50	.766	20.33
40 –45	2	3	5	17	0.29	42.7	16.90	.740	20.60
45 –50	2	4	6	19	0.32	47.8	16.80	.773	20.67
50 –55	4	9	13	21	0.62	52.4	16.80	.741	20.51
55 –60	3	9	12	23	0.52	57.3	16.84	.718	20.43
60 –65	0	8	8	25	0.34	62.0	17.24	.733	20.90
65 –70	2	3	5	27	0.19	66.3	16.88	0.721	20.48

TABLE III

(10′ Zones)

Zone	Numbers B	Numbers F	Numbers All	Area of Zone	Density N/Area	$\bar{D}$	$\bar{m}(pg)$	$\overline{\log d}$	$m+5 \log d$
0′–10′	7	5	12	4	3.00	6.2	16.21	0.689	19.65
10 –20	7	11	18	12	1.50	14.4	16.51	.702	20.02
20 –30	8	14	22	20	1.10	25.5	16.70	.726	20.33
30 –40	7	11	18	28	0.64	36.2	16.77	.751	20.52
40 –50	4	7	11	36	0.31	45.5	16.85	.758	20.64
50 –60	7	18	25	44	0.57	54.7	16.82	.730	20.47
60 –70	2	11	12	52	0.25	63.7	17.10	.728	20.74
70 –80	4	4	8	60	(0.13)	73.9	(16.52)	(.776)	20.37
80 –90	1	5	6	68	(0.09)	84.9	(16.83)	(0.776)	20.71

addition to the total numbers, the numbers in each of the two groups, B (bright) and F (faint), referred to in the last paragraph, are given separately. The width of the zones is 5′ in Table II and 10′ in Table III. The results in Table II are exhibited graphically in Figures 2 and 3.

In Figure 2 the density, i.e., the number of objects per unit area, is plotted against distance from the nucleus of M 31. The objects are conspicuously concentrated toward the nucleus, slightly more so for those in group B than for those in group F.

A few of the objects are found beyond the recognized borders of the spiral, i.e., more than 80′ from the nucleus. In order further to investigate the extreme limits of the scatter, several 100-inch reflector plates were examined, which were centered in the vicinity of

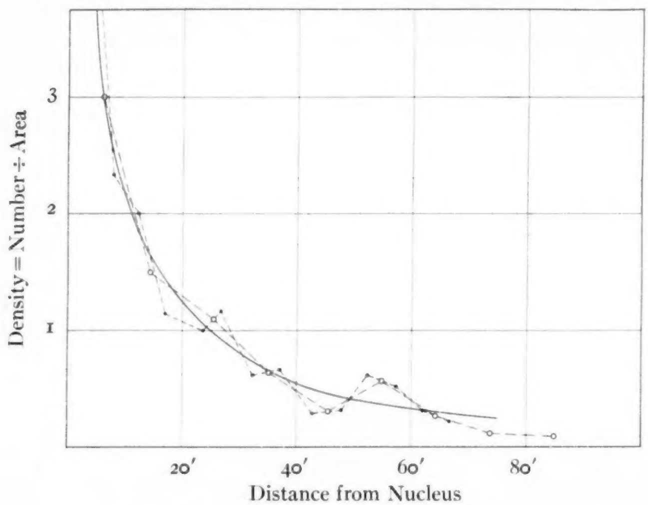


FIG. 2.—Distribution of nebulous objects with respect to the nucleus of Messier 31. Numbers of objects in successive zones divided by the areas of the zones are plotted against mean distances from the nucleus. Open circles, zones 10′ in width; dots, 5′ zones. Beyond 65′ from the nucleus the data are incomplete.

M 31 but well beyond its borders. On four plates south following the major axis, centered about 1° from the axis, one typical object, No. 140 in Table I, and two probable and five possible examples were found. If No. 140 lies in the plane of the spiral, its distance from the nucleus is about 213′. The two probable examples,[1] on the same assumption, would be at distances of 202′ and 221′, respectively. For purposes of comparison with the diameter of the galactic system as

[1] The positions of these objects are $X = -0\overset{\prime}{.}3$, $Y = -55\overset{\prime}{.}2$ and $X = +5\overset{\prime}{.}4$, $Y = -50\overset{\prime}{.}4$, with magnitudes estimated as 16.5 and 16.0, respectively. The latter appears on Pl. II. The position of No. 140 is $11\overset{\prime}{.}05$ S. following B.D. $+40^\circ 166$ and $12\overset{\prime}{.}25$ S. preceding B.D. $+40^\circ 173$.

outlined by the globular clusters, it seems possible that the diameter of M 31, as outlined by these objects, may be taken as of the order of 7°, or 100,000 light-years. As will appear later, the ratio of the diameters corresponds roughly to the systematic difference in the absolute magnitudes of the objects from which the diameters are derived.

On the north preceding side of the major axis the only plate available was centered on N.G.C. 205, the fainter companion of M 31. Eight objects were found in addition to a few distant ones listed in Table I. These new objects are concentrated about N.G.C. 205 and are probably associated with the nebula itself.[1] No similar concentration is found around the brighter companion, M 32. The most distant of the new objects, if associated with M 31 rather than with N.G.C. 205, would be about 180′ from the nucleus of the spiral.

That the brighter objects in M 31 are more concentrated toward the center than the fainter ones is also apparent in Figure 3, where the mean magnitudes for successive zones are plotted against mean distances from the nucleus. The mean luminosity decreases by about 0.75 mag. as the distance increases from about 5′ to 60′ and more. Very little of the change can be attributed to the difficulty of detecting faint objects in the nuclear region, since the influence of the luminous background is not serious beyond 5′ from the nucleus. The

[1] The objects that appear to be associated with N.G.C. 205 are marked for identification on Pls. I and II. Their positions with respect to the nucleus of the nebula, together with estimated diameters and magnitudes, are given below. The major axis of N.G.C. 205 is assumed to lie in position angle N. 9° W. X co-ordinates are positive south of the nucleus, and Y co-ordinates are positive west of the nucleus. Distances from the nucleus, D, are given with no correction for the tilt of the nebula. Co-ordinates of the nucleus with respect to the nucleus of M 31 are approximately $X=-4\overset{\prime}{.}2$, $Y=+36\overset{\prime}{.}8$.

	X	Y	D	m	d	Conc.
1	+4′.4	−0′.8	4.5	16.8	5″	m
2	+2.1	−1.4	2.6	16.7	5	m
3	+0.8	−6.2	6.2	15.4	8	m
4	+0.8	−0.3	0.9	18.2±	4	m
5	+0.3	+0.3	0.5	18.0±	3	s
6	−0.8	−0.9	1.2	18.3±	4	d
7	−1.6	−0.9	1.8	17.6	4	m
8	−7.4	+3.9	8.3	16.5	5	m

background does affect the determination of magnitudes, but its influence can be largely eliminated by using short exposures.

APPARENT DIAMETERS

The greatest effect of the background is on the estimation of diameters—the denser the background, the smaller the apparent diameter. Since diameters decrease with decreasing exposures, a direct determination of the quantitative relation is very uncertain. Some

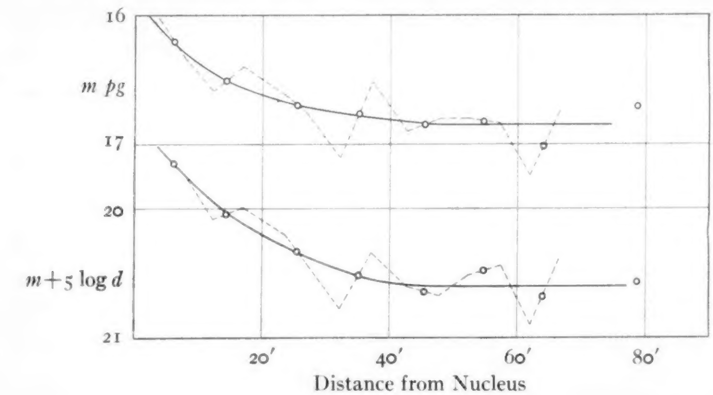


FIG. 3.—Dependence of magnitude and diameter upon distance from the nucleus of Messier 31. Above, mean magnitudes and distances of objects in successive zones concentric with the nucleus of Messier 31. Below, mean surface brightness ($m+5 \log d$) and mean distance. Open circles refer to zones 10′ in width; the broken lines to 5′ zones.

notion may be obtained, however, by inspecting the values of $m+5 \log d$ for successive zones listed in the last column of Tables II and III and plotted against distance from the nucleus of M 31 in Figure 3. These values of the surface brightness increase systematically out to about 30′ from the nucleus, but beyond this limit are reasonably constant and have a mean value of 20.6. We may therefore suppose that the effect of the background becomes negligible at about this critical distance and that the outer objects are typical of the entire group. Mean diameters corresponding to various mean magnitudes may therefore be derived from the relation

$$m+5 \log d=20.6 .$$

The results are given in Table IV.

The linear scale at the distance of M 31 is about $1'' = 1.2$ parsecs, hence the diameters appear to range from about 16 to 4 parsecs. The

TABLE IV

DIAMETERS

m	$\log d$	d	D
15.0	1.12	13″.2	15.8 parsecs
15.5	1.02	10.2	12.2
16.0	0.92	8.3	10.0
16.5	0.82	6.6	7.9
17.0	0.72	5.25	6.3
17.5	0.62	4.2	5.0
18.0	0.52	3.3	4.0

TABLE V

FREQUENCY DISTRIBUTION OF MAGNITUDES

m (pg)	Numbers			m (pg)	Numbers		
	$r<40'$	$r>40'$	All		$r<40'$	$r>40$	All
15.00	1	1	2	16.7	1	2	3
15.1	0	0	0	16.8	7	6	13
15.2	1	1	2	16.9	2	3	5
15.3	1	1	2	17.0	11	7	18
15.4	2	0	2	17.1	5	5	10
15.5	1	3	4	17.2	1	7	8
15.6	1	0	1	17.3	1	5	6
15.7	5	0	5	17.4	2	3	5
15.8	3	3	6	17.5	3	2	5
15.9	2	1	3	17.6	0	2	2
16.0	3	2	5	17.7	0	3	3
16.1	2	2	4	17.8	1	0	0
16.2	1	2	3	17.9	1	0	1
16.3	2	4	6	18.0	1	3	4
16.4	0	0	0	18.1	0	0	0
16.5	3	1	4	18.2	1	1	2
16.6	5	0	5				
				Total	70	70	140

correlation of m and $\log d$ for objects more than 30′ from the nucleus is shown in Figure 4.

FREQUENCY DISTRIBUTION OF MAGNITUDES

The data bearing on the frequency distribution of apparent magnitudes are summarized in Table IV, which gives the total numbers

of objects for each successive tenth of a magnitude, and, in addition, the corresponding numbers for the objects which are at distances less than and greater than 40′, respectively, from the nucleus of M 31. The data for all objects together are exhibited in Figure 5. The ac-

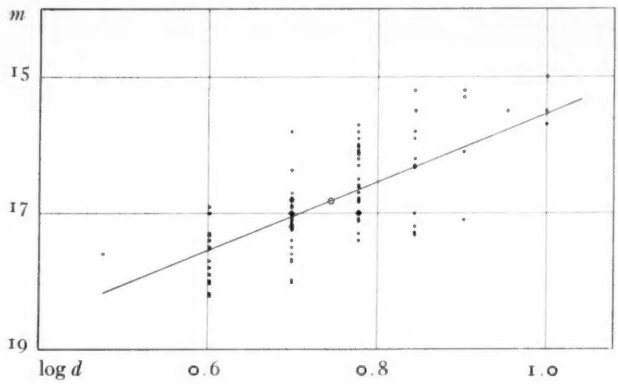


FIG. 4.—Luminosity-diameter relation for objects more than 30′ from the nucleus of Messier 31.

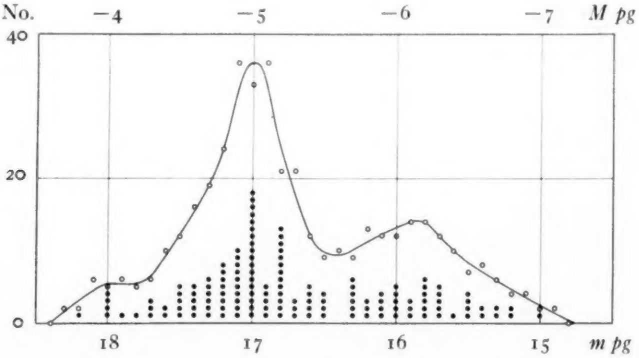


FIG. 5.—Frequency distribution of magnitudes of objects in Messier 31: dots, individual objects; circles, sums for three consecutive tenth magnitudes centered on the middle tenth.

tual counts are represented by the array of points, and the curve has been smoothed by plotting the sums of the counts for three consecutive tenths of a magnitude.

Two maxima are conspicuous, at about magnitudes 15.85 and 17.0, respectively, and the curve, as a whole, appears to be a combination of two symmetrical curves centered around the two maxima-

ma. The true maximum of the brighter curve, on this view, should be slightly brighter than that observed, and hence may be assigned the even tenth, 15.8. Since the distance modulus of M 31 is 22.0, the absolute magnitudes corresponding to the maxima are -5.0 and -6.2, respectively. The mean apparent magnitude of the entire group is about 16.7, corresponding to absolute magnitude -5.3.

The double maximum appears in the frequency-curves for each successive zone, although the numbers are so small that zones of considerable width must be used to render the phenomenon con-

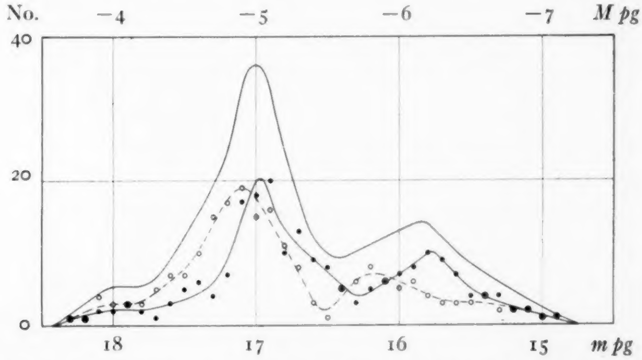


FIG. 6.—Frequency distribution of magnitudes of objects in the inner and in the outer regions of Messier 31: dots, objects less than 40′ from the nucleus; circles, objects more than 40′ from the nucleus. The top curve, representing all objects, is that shown in Fig. 5. The dots and circles represent sums for three consecutive tenth magnitudes centered on the middle tenth.

spicuous. The brighter component-curve is relatively more pronounced in the inner zones, as may be inferred from the dependence of mean magnitude upon distance from the nucleus (Fig. 3). This also appears in Figure 6, where the two curves for the zones 0′–40′ (70 objects) and the zone $>40'$ (70 objects) may be compared with one another and with the general curve copied from Figure 5. The three curves, all smoothed by the method described above, are similar in a general way, although the maxima for the outer zone appear to be displaced somewhat with respect to those for the inner zone. This feature may have some significance, since curves for the two subzones 10′–20′ and 20′–40′ are very similar to each other, while the curves for the subzones 40′–60′ and $>60'$ are also similar.

For further investigation the objects are divided into the two groups, bright and faint, suggested by the general frequency-curve, with the division point at magnitude 16.5. A careful examination of the better plates indicates no conspicuous systematic difference in the character of the images. The brighter objects appear more condensed, but this may be a photographic effect.[1] The distribution of these two groups has already been discussed—both are concentrated toward the nucleus of M 31, although the concentration is more conspicuous for the brighter objects. Although the frequency-curve indicates the mingling of two groups of objects, the data available at present seem to offer no further information on the matter.

COLOR-INDICES

Photovisual magnitudes of sixty of the objects have been estimated on plates exposed through a color filter, but as extra-focal exposures were available for only three or four of the objects, the results are not very reliable. Color-indices range from +0.4 to +1.1 mag., with a mean value of about 0.70 mag. The uncertainty of the mean is probably 0.2 mag., representing, for the most part, the possibility of systematic error in the photovisual scale as determined from a small number of extra-focal images.

The mean color-index, as it stands, corresponds to a mean spectral type of G0 or slightly earlier. This is consistent with visual estimates of color for several of the brightest objects and with the type F8 indicated by the single spectrogram available. The range in the estimated color-indices corresponds to a spectral range from about F0 to K0. This is similar to the range among the globular clusters in the galactic system, but the uncertainties in the estimates detract from the significance of the comparison.

COMPARISON WITH GLOBULAR CLUSTERS IN THE GALACTIC SYSTEM

Among known types of celestial bodies, the objects in M 31 find their closest analogy in globular clusters. The globular forms, symmetry, and spectral types are closely comparable, and no further discussion of these points is necessary. There remains, however, the comparison of luminosities and dimensions.

[1] As will appear later, the absolute luminosities of galactic globular clusters vary directly with the concentration.

Shapley's scale of magnitudes.—The most complete list of integrated photographic magnitudes and diameters of galactic globular clusters is found in Shapley's monograph on star clusters.[1] The estimates of apparent magnitudes were derived from comparisons with stars on focal exposures, and hence it is not surprising to find that they deviate widely from the usual Pogson system. Shapley characterizes his scale as "convenient but not conventional," and remarks

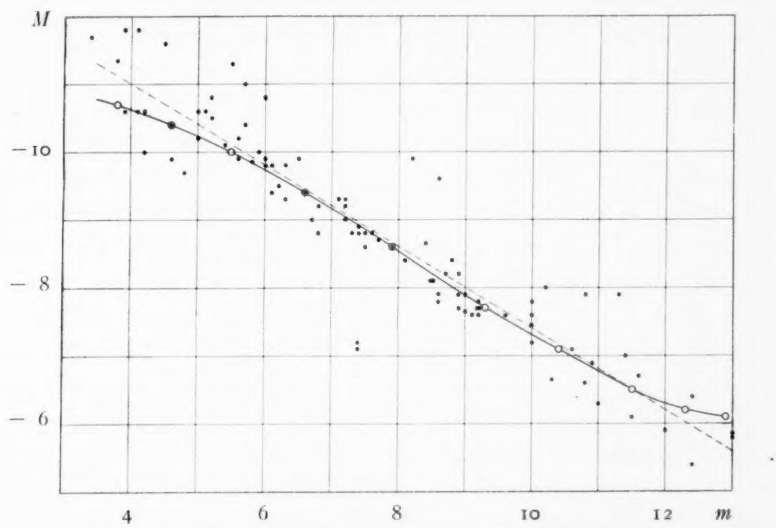


FIG. 7.—Relation between M and m on Shapley's scale of integrated magnitudes of globular clusters. The straight line represents the relation $M = 0.6\,m - 13.2$. The circles and continuous curve represent Shapley's correlation between m and $m - M$.

that his estimates of apparent luminosity range through nearly 10 mags., which "would indicate a factor of 100 in the relative distances, rather than the factor of 10 which is actually found."

On Shapley's scale the apparent magnitudes show an approximately linear correlation with the absolute magnitudes. This correlation, which appears in Shapley's monograph[2] as a relation between m and $m - M$, is exhibited directly in Figure 7 in order to emphasize the relatively small scatter of the points about the correlation-curve. As m ranges from 3 to 12, M varies systematically from about -11.3

[1] *Star Clusters*, "Harvard Observatory Monographs," No. 2, 1930.

[2] *Ibid.*, pp. 164–165, Fig. XI (2), and Table XI (IV).

to about -6. It is obvious that some sort of calibration is necessary before the clusters can be compared with other objects.

The straight line in Figure 7 appears to be a fair first approximation to the correlation between m and M, but Shapley, using various refinements, arrives at the non-linear form indicated by the open circles (derived from his relation between m and $m-M$). If we assume no correlation between M and m on the conventional scale or, what amounts to the same thing, since distances, and hence the values of M, are based on the luminosity of stars, no correlation between the absolute magnitudes of clusters and of their brightest stars, then the correlation-curve in Figure 7 indicates the deviation of Shapley's scale of cluster magnitudes from Pogson's scale. Shapley's correlation-curve indicates a systematic deviation of 4.6 mag. in the interval 3.1–12.2. The deviation seems large, but a smaller value would leave a correlation between m and M to be explained away, as well as one between M and distance from the observer.[1]

The order of the deviation appears to be confirmed by Holetschek's visual magnitudes of forty-four clusters as corrected by Hopmann.[2] These data conform approximately to the Pogson scale —at least they represent a deliberate attempt in that direction by an observer of wide experience in measuring the luminosity of comets. They are in fair agreement with other less extensive lists of visual magnitudes of clusters, and for the fainter objects the analogy with nebulae, for which Holetschek's measures are known to be of the proper order, offers circumstantial evidence of considerable weight.

A plot of Shapley's photographic magnitudes against the differences Holetschek − Shapley is shown in Figure 8. An approximately linear correlation is suggested, but the precise slope is difficult to

[1] Since the correlation holds for clusters more than 45° from the direction of the center of the galactic system as well as for clusters less than 45° from the center, the relation is between M and distance, not from the center of the system, but from the observer. The relation is in the sense that the nearer clusters are the brighter.

[2] *Annalen der Wiener Sternwarte*, **20**, 1907. The revision by Hopmann (*Astronomische Nachrichten*, **214**, 425, 1921) consists in photometric measures of the comparison stars to replace the *BD* magnitudes used by Holetschek. As not every comparison star was measured, the corrections are provisional. The corrections probably become appreciable between magnitudes 6 and 7, say 6.5, reach about +0.3 at 8.5, +0.6 at 9.0, and +1.1 at 9.5, beyond which they are presumed to be about constant at the value last mentioned.

determine. The full line bisects the angle made by the regression-curves derived from the data when the two discordant points, $m_s = 7.3$, $H-S = 4.0$ (N.G.C. 5897) and $m_s = 7.5$, $H-S = 3.1$ (N.G.C. 6681), are omitted. It represents the relation

$$H-S = 4.23 - 0.446 m_s \; .$$

This formula indicates a deviation of about 4 mag. over the range 3.1–12.2, as compared with 5.3 for the linear correlation in Figure 7 or with the value 4.6 given by Shapley's curve.

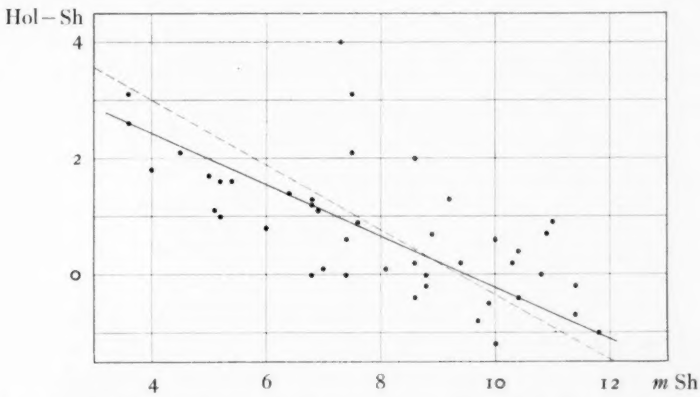


FIG. 8.—Relation between Shapley's photographic and Holetschek's visual magnitudes of globular clusters. The full line, Hol – Sh = 4.23 – 0.446 Sh, represents the correlation when the two most discordant points are omitted. The broken line, Hol – Sh = 5.25 – 0.56 Sh, represents the correlation when all data are included.

When the discordant points are included, i.e., when all the data are used, the same procedure leads to the relation

$$H-S = 5.25 - 0.56 m_s \; .$$

The slope of this line closely approximates that of the straight line in Figure 7, the deviations being 5.1 for the former and 5.3 for the latter. The unsymmetrical distribution of the residuals detracts from the value of the comparison and, in fact, suggests that further analysis of the material is scarcely profitable. It is clear, however, that Holetschek's data confirm the general order of the correction to Shapley's scale derived on the assumption that, on the conventional scale, M is independent of m.

Zero-point of Shapley's scale.—Figure 8 further indicates that the zero-point, i.e., the point at which Shapley's scale coincides with the conventional scale, is probably in the vicinity of $m_s = 11$, since in that region the differences Shapley − Holetschek approximate the color-indices of clusters in general. This conclusion is consistent with fragmentary evidence from a few extra-focal images of faint clusters and also with photo-electric-cell measures made by Professor Stebbins with the large reflectors at Mount Wilson.

The measures by Stebbins are unpublished, but he very kindly permits me to quote some of the results, which include determinations of colors and of photo-electric-cell magnitudes (practically equivalent to photographic magnitudes) through apertures of different dimensions. The accuracy is of a higher order than that possible with the methods usually applied to the measurement of clusters. By plotting magnitudes against diameters of apertures for individual objects it is possible to derive total magnitudes, diameters, and magnitudes for arbitrarily selected diameters. Results are at present available for only five objects—N.G.C. 2419, 6760, 6779, 6864, and 7006. The diameters appear to be greater than those estimated by Shapley. The mean values of the magnitudes are as follows:

Shapley	10.2
Stebbins	10.5*
Stebbins	10.7†

* Total magnitude.
† Magnitude corresponding to Shapley's diameter.

The zero-point is determined by the correction 0.3 mag. required at $m_s = 10.2$. Inspection of Shapley's correlation in Figure 7 indicates that at $m_s = 10.8$ the curve is 0.3 mag. lower than at $m_s = 10.2$. Hence the zero-point may be taken at 10.8, which is in good agreement with the value 11.0 suggested by Holetschek's data. The corresponding corrections to Shapley's magnitudes are in Table VI.

The zero-point may be somewhat uncertain, since it is derived from a limited number of objects; but it is based on the most accurate measures available and is consistent with data from other sources.

Comparison of absolute magnitudes.—On the basis of the corrections in Table VI, the mean M of the ninety-three globular clusters

in Shapley's catalogue is -6.77. The frequency distribution of the magnitudes is shown in Figure 9, the curve being smoothed by the method used for the curves relating to the objects in M 31. The two exceptionally bright clusters are N.G.C. 6356 and 6864, noted by Shapley as peculiar.

If these two isolated clusters are omitted, the range is from -5.4 to -7.6, as compared with -4 to -7 for the objects in M 31. Two maxima are suggested, at about -5.75 and -6.95, as compared

TABLE VI

CORRECTIONS TO SHAPLEY'S SCALE

Shapley m	Corr.	M_{pg}	Shapley m	Corr.	M_{pg}
3	+4.0	7.0	8	+1.6	9.6
4	3.8	7.8	9	+1.0	10.0
5	3.4	8.4	10	+0.4	10.4
6	2.8	8.8	11	−0.1	10.9
7	+2.2	9.2	12	−0.5	11.5

with those at -5 and -6.2 in M 31; but the relative numbers in the groups are reversed. In the galactic system the brighter group dominates the distribution and the fainter group is inconspicuous.[1] In M 31 the fainter group dominates, and only one-quarter of the total number can be assigned to the brighter group.

The most favorable agreement between the absolute magnitudes of the objects in the two systems is obtained by accepting the reality of the double maxima; the galactic globular clusters are then systematically brighter than the objects in M 31 by about 0.75 mag. The least favorable agreement follows on comparing the most fre-

[1] The fainter secondary group of globular clusters consists almost entirely of the looser clusters—Shapley's classes IX–XII. Among these classes the double maximum is conspicuous, and it is the fainter group which appears in Fig. 9, the brighter being lost among the more concentrated clusters. This suggests the possibility that the objects in M 31 may be analogous to the looser clusters in the galactic system.

In general, the luminosity of clusters decreases with the concentration:

Class	No.	$\bar{M}$
I–IV	27	−7.14 (−7.02, omitting N.G.C. 6356 and 6864)
V–VIII	34	6.94
IV–XII	32	−6.24

quent magnitudes, the double maxima being disregarded. The systematic difference is then about 1.95 mag. The difference in the mean magnitudes of all objects is intermediate—about 1.5 mag.

The two groups, however, overlap to a very considerable extent, and the brighter objects in M 31 are strictly comparable with the most frequent types of globular clusters. The systematic differences, which range from about 0.75 to 2 mag. according to the interpretation of the data, are sufficiently small to suggest that the objects in M 31 should be provisionally classed with the clusters.

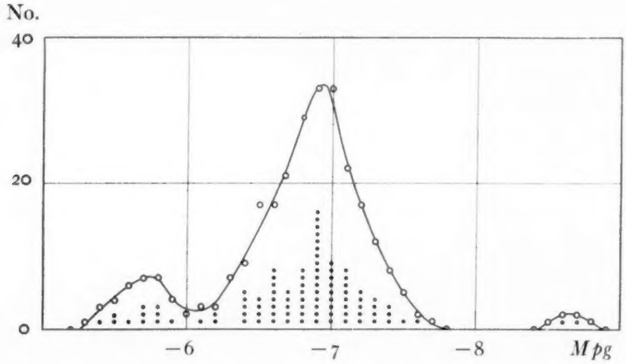


Fig. 9.—Frequency distribution of absolute photographic magnitudes among globular clusters in the galactic system: dots, individual clusters; open circles, sums for three consecutive tenth magnitudes centered on the middle tenth. The two very bright isolated clusters are N.G.C. 6356 and 6864.

Comparison of diameters.—A comparison of diameters is difficult since the criteria used in the estimations are necessarily rather arbitrary. Shapley's estimates of apparent diameters of clusters vary directly with the corresponding absolute diameters, but not in the same manner that his apparent luminosities vary with the absolute luminosities. His apparent magnitudes and the logarithms of his diameters approximate a linear relation, with a considerable scatter introduced by the looser clusters, but the slope of the correlation-curve does not conform to the relation $m+5 \log d = \text{Const.}$ The mean value of the constant for all clusters is 20.97 (clusters) as against 20.6 for the objects in M 31. For the calculation, d is expressed in seconds of arc and the magnitudes are reduced to the conventional scale. The value of the constant for the galactic globular clusters

ranges, however, from about 19.4 for $m = 11.5$ to about 22.3 for $m = 8$. Around $m = 9.5$ it approximates the value observed in M 31.

The absolute diameters as derived from the apparent diameters and distances range from about 6 to 50 parsecs as compared with a range from about 4 to 16 parsecs for the objects observed in M 31. There is thus some overlap, regardless of uncertainties in the criteria employed.

COMPARISON WITH GLOBULAR CLUSTERS IN THE MAGELLANIC CLOUDS

A comparison with globular clusters in the Magellanic Clouds is perhaps more significant, since the distance of M 31 is determined in terms of the distance of the Small Cloud and since, moreover, Shapley's magnitudes of the clusters are in the region where the scale corrections are relatively unimportant. Shapley reports two clusters in the Small Cloud,[1] but regards the fainter as somewhat uncertain. His magnitudes are 11.3 and 10.2, corresponding to conventional magnitudes 11.1 and 10.5. Since $m - M = 17.3$ for the Cloud, the absolute magnitudes of the clusters are -6.2 and -6.8, the mean being -6.5. Since the diameters are $0\overset{'}{.}9$ and $1\overset{'}{.}4$, respectively, corresponding to $6\overset{''}{.}4$ and $9\overset{''}{.}9$ at the distance of M 31, these clusters are strictly comparable with the brighter objects in M 31. It is uncertain, of course, whether the comparison should be made with the brighter objects in M 31 or with the mean of all. In the latter case the discrepancy would be 1.2 mag., but it is reasonable to suppose that no brighter clusters are associated with the Cloud and hence that any others that may be found would decrease the discrepancy.

Eight clusters are reported in the Large Cloud.[2] These are listed in Table VII with Shapley's magnitudes, diameters, and, in addition, the revised absolute magnitudes and apparent diameters corresponding to the distance of M 31. Shapley suggests the possibility that of the two brightest clusters the brighter may be a foreground object and the fainter, a cluster of a type other than globular.

The revised absolute magnitudes range from -7.5 to -6.4 with a mean value of -6.8, and hence are comparable with those of the brighter objects in M 31. The brightest cluster, which Shapley sug-

[1] *Op. cit.*, p. 187, Table XIII (I). [2] *Ibid.*

gests may be a field object, is above the upper limit of the objects in M 31 by 0.5 mag. The diameters also are consistent, averaging somewhat less than those in M 31 for objects of the same luminosity. As in the case of the Small Cloud, there is the uncertainty as to whether the comparison should be with the brighter objects in M 31 or with the mean of all.

The general conclusion appears to be that the analogy between the objects in M 31 and the known globular clusters is too close to be

TABLE VII

GLOBULAR CLUSTERS IN LARGE MAGELLANIC CLOUD

N.G.C.	Shapley		M	d at Distance of M 31
	d	m		
1783	1.4	10.1	−6.6	8.8
1806	0.9	10.6	6.4	5.7
1831	1.3	10.0	6.7	8.2
1835	1.2	9.8	6.8	7.6
1846	1.2	10.4	6.5	7.6
1856	2.1	8.8	7.2	13.3
1866	2.2	8.0	7.5	13.9
1978	1.0	10.2	−6.6	6.3
Mean	....	....	−6.8	....

ignored and that, provisionally at least, they should both be included in a single class. The significance of the double maximum in the frequency distribution, i.e., the possibility of subclasses whose relative richness varies from system to system, is a matter for further investigation. The present comparisons involve several approximations and, of course, assume the validity of Shapley's scale of distances. More reliable results will be derived when the scale of cluster magnitudes and effects of obscuration in both the galactic system and M 31 have been determined.

SIMILAR OBJECTS IN OTHER NEBULAE

The subject is further complicated by the examination of other nebulae. In M 33 some twelve or fifteen objects may be of the type under discussion, but they average about 1.5 mag. fainter than those in M 31, although the latter nebula is slightly more distant. Several brighter objects in M 33 were examined as possibly of the type

under discussion, but in each case a negative color-index differentiated them, and on the best plates it was generally possible to detect a sharp star image on a nebulous background.

N.G.C. 6822 may be analogous to M 33. A few objects found in N.G.C. 6822 were discussed in a former investigation of that system,[1] and on the basis of luminosities and dimensions were assumed to be field nebulae. The new data from M 31 and M 33 appear to reopen the question of their status.

In M 101, on the other hand, a half-dozen apparently typical objects are found, the brightest being about 1 mag. fainter than the brightest in M 31. The difference is consistent with the relative apparent luminosities of variables and brightest stars in the two nebulae. Other bright knots in M 101 have been identified as patches of emission nebulosity surrounding early-type stars. These are common features of late-type spirals and irregular nebulae and generally exhibit an appreciable lack of symmetry.

Among the numerous other conspicuous nebulae for which suitable plates are available, the suspected objects have been identified with confidence only in M 81, although a few questionable cases have been reserved for further investigation. It seems improbable, however, that the existence of these objects can seriously affect the validity of the apparent photographic magnitudes of the brightest stars as a statistical criterion of nebular distances.

Carnegie Institution of Washington
Mount Wilson Observatory
February 1932

[1] *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, **62**, 409, 1925.

MAGNITUDES AND COLOR INDICES OF CERTAIN STARS OF CLASSES B AND A

By F. E. CARR

ABSTRACT

Magnitudes, photographic and *photovisual*, and *color indices* have been measured for 95 H.D. stars of B and A type found on central portions of plates taken by F. E. Ross and R. S. Zug (Table I). The procedure of measurement is the same as that given.

The graph (Fig. 1) for individual color indices according to spectral type *shows considerable dispersion* and is of the same order as that found in Yerkes and Mount Wilson determinations. The mean color indices are stated in Table II and shown in graphical form in Figure 2.

The mean color indices are about 0^M10 higher than those found at Yerkes and differ by a somewhat less figure from the Mount Wilson results for stars of the same order of brightness (mag. 7–10).

The magnitudes and color indices of stars listed in the present paper are supplementary to, and obtained from, the same plates as those published by F. E. Ross and R. S. Zug in *Astronomische Nachrichten*, **239**, No. 5728, 16.[1] As their list (compiled by Kopff as comparison stars for Eros) contained relatively few A and B stars, the author undertook, at the suggestion of Dr. Ross, to measure by the same method the magnitudes of about one hundred stars of the types mentioned, taken from the *Henry Draper Catalogue* and found within $4\frac{1}{2}°$ of the centers of the plates covering the first three fields of the series by Ross and Zug.

A complete description of the equipment and procedure will be found in the paper referred to. It might be added that at least two exposures were made on each field, but the centers were so chosen that the plates overlapped, and each star appears on at least four plates. Each magnitude in general is based on four measurements, but in certain cases stars were included within the prescribed radius for one pair of plates, but outside of it for the adjacent pair. For such stars only two measurements were used, as indicated in the table.

[1] The plates taken with the twin 3-inch cameras of the Bruce telescope designed by Dr. F. E. Ross, $a=76$ mm and $f=534$ mm. The photographic camera was stopped down to 42 mm. The measurements were made at the Yerkes Observatory during the summer of 1930 with the use of the artificial scale of images constructed by Ross and Zug.

As the scale-readings were all made by one person, they cannot be considered free from bias, but it is thought that all gross errors have been eliminated.

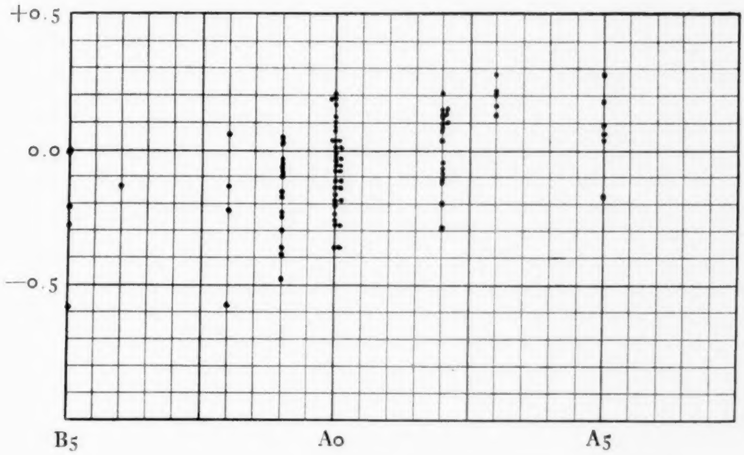


FIG. 1

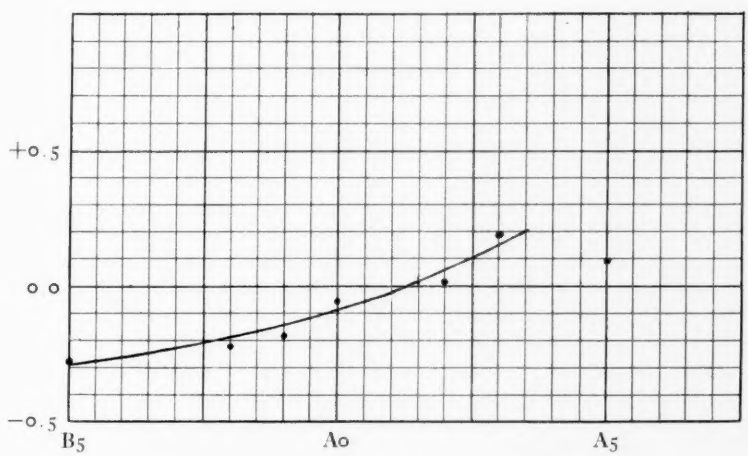


FIG. 2

Table No. I contains in the order of the *Henry Draper Catalogue* numbering the finally adopted photovisual and photographic magnitudes, the number of plates used, the color index, and the spectral class. The individual values of color index are plotted in Figure 1

TABLE I

H.D. No.	Photovisual Mag.	Plates	Photographic Mag.	Plates	C.I.	Sp.
37736	$7^M.86$	2	$7^M.66$	4	$-0^M.20$	A2
38060	9.36	4	9.46	4	+ .10	A0
38179	8.12	4	7.88	4	− .24	B9
38188	8.03	4	8.06	4	+ .03	A0
38245	8.60	4	8.72	4	+ .12	A0
38258	7.52	4	7.30	4	− .22	B8
38287	8.80	4	8.98	4	+ .18	A0
38502	8.60	2	8.79	2	+ .19	A0
38730	8.23	4	8.17	4	− .06	A0
38817	7.63	4	7.79	4	+ .16	A2
38832	8.70	4	8.79	4	+ .09	A2
38850	8.53	4	8.36	4	− .17	B9
38943	9.23	4	9.15	4	− .08	A0
38959	9.22	4	9.43	4	+ .21	A2
39153	9.14	4	9.23	4	+ .09	A0
39181	9.41	4	9.61	4	+ .20	A3
39250	8.72	4	8.89	4	+ .17	A0
39272	9.28	4	9.15	4	− .13	A0
39432	9.15	3	9.18	4	+ .03	A2
39553	8.74	4	8.37	4	− .37	A0
39966	9.14	4	9.22	4	+ .08	A0
40131	8.04	4	7.83	4	− .21	A0
40143	6.81	4	6.81	4	0.00	A0
40160	7.70	3	7.12	4	− .58	B5
40206	8.00	4	7.93	4	− .07	A0
40278	8.70	4	8.70	4	0.00	B9
40279	7.70	4	7.86	4	+ .16	A6
40326	8.16	4	8.00	4	− .16	B9
40344	8.86	4	8.96	4	+ .10	A2
40470	7.74	4	7.83	4	+ .09	A0
40471	8.89	4	8.60	3	− .29	A2
40562	8.79	4	8.63	2	− .16	B9
40586	8.39	4	8.37	4	− .02	A0
40694	8.21	2	8.27	2	+ .06	B8
40754	9.10	4	9.11	4	+ .01	A0
40785	8.86	4	8.82	4	− .04	A2
40830	8.20	4	7.81	4	− .39	B9
40957	7.32	4	7.45	4	+ .13	A2
40978	7.08	4	6.89	4	− .19	B3
41114	8.49	4	8.52	4	+ .03	A0
41161	6.57	2	6.44	2	− .13	B6
41238	9.01	4	9.29	4	+ .28	A5
41250	9.00	4	8.92	4	− .08	A2
41477	8.93	2	8.91	2	− .02	A0
41522	9.04	2	9.12	2	+ .08	A0
41541	7.09	2	6.81	2	− .28	B5
41578	7.62	2	7.56	6	− .06	A0
41591	8.76	2	8.53	2	− .23	B9
41707	9.10	4	8.99	4	− .11	A2
41806	9.20	2	8.92	2	− .28	A0
41847	7.19	2	7.07	2	− .12	A0
41866	8.41	4	8.48	4	+ .07	A0
42013	8.65	1	8.17	2	−0.48	B9

TABLE I—*Continued*

H.D. No.	Photovisual Mag.	Plates	Photographic Mag.	Plates	C.I.	Sp.
42063	8^M49	4	8^M41	2	-0^M08	A0
42064	9.37	2	9.33	2	− .04	A0
42084	6.83	4	7.10	4	+ .27	A3
42173	7.59	4	7.74	4	+ .15	A2
42232	8.60	4	8.30	4	− .30	B9
42331	9.06	4	8.94	4	− .12	A0
42350	7.59	4	7.56	4	− .03	B9
42418	8.19	4	8.37	4	+ .18	A0
42431	9.40	3	9.50	4	+ .10	A2
42470	9.46	4	9.63	4	+ .17	A5
42757	8.26	4	8.35	4	+ .09	A5
42782	7.03	4	6.81	4	− .22	B5
42783	7.84	4	7.27	4	− .57	B8
42892	8.60	4	8.30	4	− .30	A0
43058	9.16	2	9.37	2	+ .21	A3
43126	9.04	4	8.83	4	− .21	A0
43127	9.70	2	9.52	2	− .18	A5
43184	7.86	4	7.90	4	+ .04	A5
43280	8.29	4	8.33	4	+ .04	A0
43457	8.95	2	9.11	2	+ .16	A3
43794	8.07	4	7.93	4	− .14	A0
43854	9.64	4	9.78	4	+ .14	A2
43962	8.67	4	10.40	4	+1.73	M0
44124	7.39	4	7.32	4	−0.07	A2
44125	8.04	4	8.10	4	+ .06	A5
44249	8.08	4	7.71	4	− .37	B9
44281	8.28	4	7.91	2	− .37	A0
44387	9.43	4	9.43	4	.00	B5
44612	7.39	2	7.11	4	− .28	A0
44651	8.15	4	8.27	4	+ .12	A3
44692	7.99	4	7.72	4	− .27	A0
44809	8.79	2	8.92	2	+ .13	A2
44831	8.21	4	8.07	4	− .14	B8
44832	8.26	4	8.30	4	+ .04	B9
45105	6.56	4	6.50	4	− .06	B9
45349	8.82	4	8.72	4	− .10	B9
45370	8.98	4	8.94	4	− .04	A0
45390	9.51	3	9.39	4	− .12	A2
45670	9.29	4	9.13	4	− .16	A0
45781	9.05	4	9.04	4	− .01	A0
45782	6.75	2	6.74	2	− .01	A0
45621	8.68	4	8.71	4	+0.03	B9

against spectral type. The dispersion in color index for each type is of about the same extent as found by Ross and Zug at Yerkes, and by Seares, Sitterly, and Joyner[1] at Mount Wilson, for the Eros comparison stars.

[1] *Contribution from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 415.

The mean values are collected in Table II and plotted in Figure 2. Those groups containing only a single star are omitted, as is also

TABLE II

Spectrum	Color Index	No. Stars
B5	−0.27	4
B8	− .22	4
B9	− .18	15
A0	− .05	40
A2	+ .02	18
A3	+ .19	5
A5	+0.08	6

No. 42469, which is obviously irregular. The mean color index of the A0 stars is $-0^{\mathrm{M}}.05$, which is about $0^{\mathrm{M}}.10$ higher in algebraic value than that found at Yerkes, and approximately the same as found at Mount Wilson, for stars of the same order of brightness.

Oberlin College

NOTE ON THE HYDROGEN EMISSION OF κ DRACONIS

By M. K. JESSUP

ABSTRACT

Measures of the *intensity* of the double *emission line in Hβ* in the spectrum of κ *Draconis* from spectrograms obtained in the interval 1902–1931 *indicate an approximate period* of twenty-three years for the *variation in intensity*. This result is in good agreement with the periods found by O. Struve and by Miss C. Payne.

With the beginning of the 1932 season, it appears that the intensity of the double emission in the $H\beta$ line of κ Draconis has reached a minimum for the second time in the history of spectroscopic observation of this star.

Beginning with 1912, the Ann Arbor plates form an almost continuous series. The emission is definitely present in 1912. In 1915 it has approximately reached a maximum from which it slowly falls off to minimum once more in the seasons of 1931 and 1932.

Through the kindness of Dr. Frost it has been possible to examine the Yerkes plates; the emission was measured on those plates which antedate the Ann Arbor series. There are three of these that are strong enough to be readily measurable with the Hartmann microphotometer: one for the year 1902, one in 1904, and one in 1911. The 1911 plate shows definite double emission while this is not apparent in 1904.

Miss Payne writes as follows regarding the Harvard plates:

> The main part of the Harvard data is a long series of objective prism plates made in 1888–1893. During this interval all the plates show a gradual increase in the intensity of $H\beta$ which in 1893 was of considerable strength for a star of this type. $H\gamma$ appears as a bright line from September, 1892, to June, 1893, and $H\delta$ is seen as a bright line in June, 1893.

This description would fit very well for the Ann Arbor plates of 1912–1916, during which time the intensity of $H\beta$ increased rapidly. Since emission seldom appears in lines on the violet side of $H\gamma$, except when $H\beta$ and $H\gamma$ show a maximum, it is considered that the presence of $H\delta$ emission in 1893 fixes the time of the maximum to a close approximation. In the absence of more accurate data, we may assume that the maximum of the early nineties was of about the same intensity as that of 1915.

If these assumptions are permitted, the accompanying curve (Fig. 1) may be drawn and we can arrive at an approximate period of twenty-three years for the variation of $H\beta$ emission intensity.

The measures shown in the graph were made with the Hartmann microphotometer and show difference in magnitude of the $H\beta$ emission with respect to the continuous background. The continuous spectrum was measured at two points, one under the Titanium comparison line at 4841 and the other under the Titanium line at 4856,

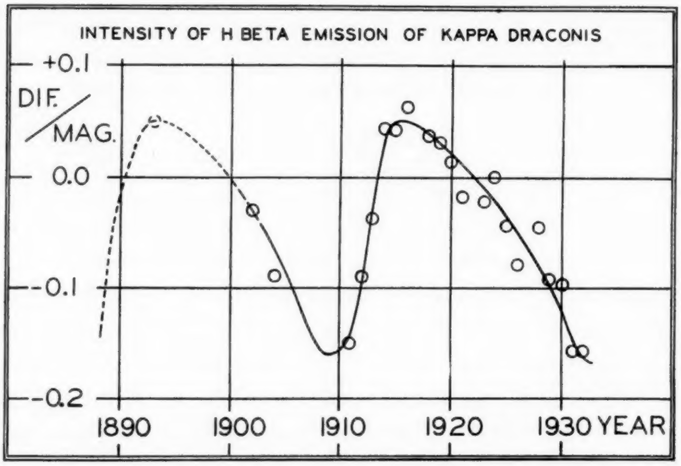


Fig. 1

and the emission line was referred to the mean of these two measures. It is possible that the extreme wings of the hydrogen absorption may extend this far from the center of the line, but if so, they have little, if any, effect.

It is of interest to notice that O. Struve[1] has suggested a period of thirty years for the variation of the intensity of the hydrogen lines in this star, with the further suggestion that the observations are too few to exclude the possibility of a shorter period. Miss Payne has suggested in her letter to the writer that perhaps a period of in the neighborhood of twenty years would approximately satisfy the available information. Both these results are in very good agreement with the present period.

The Observatory
University of Michigan
February 27, 1932

[1] *Popular Astronomy*, **33**, 596, 1925.

MINOR CONTRIBUTIONS AND NOTES

AN ABSORPTION LINE OF C IV IN STELLAR SPECTRA

ABSTRACT

An *absorption line at* λ 4658.41, observed in O-type stars, is probably identical with *C IV 4658.64*. This line has the distinction of requiring *the greatest energy of excitation* of any line yet observed in stellar absorption spectra.

The spectrum of *C* IV has recently been analyzed by B. Edlén and J. Stenman.[1] Within the region which can be photographed in stellar spectra, there appear the four lines tabulated.

Wave-Length (Air)	Int.	Designation
4441.65	1	5^2P-6^2D
4658.64	5	5^2G-6^2H
5801.51	4	$3^2S_{\frac{1}{2}}-3^2P_{\frac{3}{2}}$
5812.14	3	$3^2S_{\frac{1}{2}}-3^2P_{\frac{1}{2}}$

Stellar spectra of class O, and possibly of B0 and B1, show a weak absorption line at λ 4658.41 which has not otherwise been identified.[2] Upon examination of the spectrograms of many stars it was found that in 10 Lacertae, of class O9, this line is fairly strong. There is a suspicion that it is in reality a close double, one component of which is probably identical with the carbon line, while the other remains unidentified. The line λ 4658 appears also in one or two other O stars, for example, in λ Orionis. In stars of classes B0 and B1 it is extremely weak, and possibly not real.

The successive ionization potentials of *C* IV are:[3] 11.2, 24.3, 47.6, and 64 volts. The excitation potential of the lower state of the *C* IV line, λ 4658.64, is 55 volts. Since the excitation potentials of the lines of *He* II, which are strong in O stars, are of the order of 50 volts, it is almost certain that our identification is correct. The line at λ 4441.65 is too weak to be observed in absorption; λ 5801 and λ 5812 are

[1] *Zeitschrift für Physik*, **66**, 328, 1930.

[2] O. Struve, *Astrophysical Journal*, **74**, 225, 1931.

[3] Edlén, *Nature*, **127**, 744, 1931; L. Pauling and S. Goudsmit, *The Structure of Line Spectra*, p. 168, New York, 1930.

outside the region in which accurate measurements of stellar absorption spectra have been made.

It may be noted that Miss C. E. Moore[1] and B. Edlén[2] have identified λ 5801 and λ 5812 with emission lines in Wolf-Rayet stars recently tabulated by C. S. Beals.[3] Because of the great widths of all emission lines in these stars, *C* IV λ 4658 is blended with several strong lines of *C* III and therefore cannot be identified with certainty.

The line *C* IV λ 4658 has the distinction of requiring the greatest energy of excitation of any line yet observed in stellar absorption spectra.

J. E. Mack
P. Swings
O. Struve

March 30, 1932

[1] Private communication. Miss Moore has also called our attention to the probable identification of stellar λ 4658.41 with *C* IV.

[2] *Arkiv för Matematik, Astronomi och Fysik*, 22, B, No. 11, 1931; *The Observatory* **55**, 115, 1932.

[3] *Publications of the Dominion Astrophysical Observatory, Victoria*, 4, 271, 1930.

REVIEWS

Scientific Inference. By HAROLD JEFFREYS. Macmillan Co., 1931. Pp. vi+243. $3.50.

This work arose out of a series of papers, published jointly by the author and Dr. Dorothy Wrinch, which appeared in the *Philosophical Magazine* and *Nature*. The fundamental problem is the question of the nature of scientific inference. Starting with the postulate that "it is possible to learn from experience and to make inferences from it beyond the data directly known by sensation," Jeffreys attempts to justify the high probabilities attached in practice to simple quantitative laws. According to the author, his interest in the subject was stimulated by the fact that, in his work on subjects of cosmogony and geophysics, "it has habitually been necessary to apply physical laws far beyond their original range of verification in both time and distance, and the problems involved in such extrapolations have therefore always been prominent."

The book begins with a short discussion of logic and scientific inference, the essential object of the latter being to increase knowledge. Since the notion of probability is fundamental in scientific inference, chapters are devoted to the theory of probability and sampling. Judging from the many references to J. M. Keynes's *Treatise on Probability* (Macmillan Co.) and the contents of the first portion of the book, Jeffreys' ideas have been largely influenced by the work of J. M. Keynes and W. E. Johnson. First Jeffreys regards probability as an undefined concept—a notion traceable to Leibnitz—that expresses a relation between two propositions: thus, in the case of scientific inference, the relation of the laws of science to the data of observation. Jeffreys, however, differs from Keynes's *Treatise* and takes the stand with earlier writers—that all probabilities are expressible by numbers—and proceeds to construct postulates and set conventions, so that every probability can be associated with a real number, rational or irrational, in the interval 0 to 1. Furthermore, he postulates the unique existence of a probability number for every proposition, given a set of data. Jeffreys' treatment of probability is rather brief and, from the standpoint of a logical development, is inferior to the more symbolic treatment of Keynes. Thus, no requirement of consistency in data is made in Jeffreys' postulate for the existence of a probability; equal prob-

abilities are essential in the development of the theory but there is no explicit statement of their existence; and terms such as "impossibility," "certainty," and "mutually exclusive" are employed with neither a definition nor an indication that they are undefined concepts. Furthermore, the notation $P(p|q)$ for the probability of the proposition p, given the data q, seems needlessly cumbersome by the addition of the letter P. Nevertheless, as a description of a method capable of more rigorous demonstration, it is entirely satisfactory. The usual laws of addition and multiplication are given along with the formulae of inverse probability (Bayes's theorem). The latter is fundamental for *Scientific Inference* and it indicates an answer to the question: Given the composition of the sample, what inferences can be drawn about the composition of the whole class? The usual formula for the probability a posteriori is derived in terms of the a priori probabilities of possible composition for the whole class and a normal law approximation is found valid, if the variation in prior probabilities is not too large. Jeffreys considers a simple problem in attribute sampling and, since in this case the number of possible compositions for the whole class is finite, proves that, as the sample increases, the effect of the a priori probabilities becomes in general negligible or, as he expresses it, "we swamp the prior probability."

Jeffreys passes from the urn problem, applies inverse probability to quantitative laws, and proceeds to determine probabilities for the latter. Here the problem is quite different, for an infinite number of laws satisfies any finite number of physical measurements. But, according to Jeffreys, "however sceptical one may be about a given law that is consistent with the known facts, one would consider its probability finite," and hence, since the sum of the probabilities for the set of all "mutually inconsistent laws" (whatever meaning he wishes to imply by these terms) consistent with the known facts must be unity, the set must be denumerable and all general laws cannot have the same probability. One may challenge Jeffreys' notion about the degree of skepticism of skeptics and therefore question the conclusions thus obtained, but inasmuch as he neglects to state the premises for these probabilities and as, according to him and to other followers of the undefined concept, probability is always relative to certain given data or knowledge, one must postpone this challenge. However, this is a minor point, for without these conclusions Jeffreys' theory of scientific inference would be impossible.

We discover next in Jeffreys' created universe the idea of simplicity in general laws—"a property easily recognizable"—and "the order of de-

creasing simplicity among laws is also the order of decreasing prior probability." It is interesting to note that the notion of "simplicity" is so well defined in the author's mind that he omits explicitly to mention his assumption of a definite order to general laws in simplicity. Again one could question the assumption, but after reading in the daily press ordered lists of the names of the greatest men of all times and seeing photographs of the winners of beauty contests, it might seem reasonable. Furthermore, this assumption simplifies matters and evidently Jeffreys' universe is simple. Although probability begins and ends with probability and thus beginning and end are both undefined and no great harm has been done, nevertheless, after a clever bit of arguing, the purpose of which is to maintain the Jeffreys structure, he arrives at the principle that "every quantitative law can be expressed as a differential equation of finite order and degree, in which the numerical coefficients are integers." No longer dare one murmur "*ex nihilo nihil.*"

Jeffreys then tells us how to arrange these equations according to simplicity and even ventures so far as to suggest a definition for complexity, namely, the sum of the order, the degree, and the absolute value of the coefficients. He disappoints the reader when he fails to write down an explicit expression for the probability as a function of complexity. But, as an example of the power of his methods, he shows how "we could discard at sight the suggestion that the perihelion of Mercury could be explained if the attraction of the sun varied inversely as the 2,000,000,016 power of the distance instead of as the exact inverse square. The exiguous prior probability of such a law puts it beyond consideration, apart from the inconsistency with the observed motion of the moon's perigee that led to its abandonment." The procedure adopted to arrive at this last result is also simple, for after the force equation is cleared of decimals and only integers remain, its Jeffreys rank in complexity is somewhere in the millions. It is not clear why a little differentiation might not eliminate the awkward coefficient and—still in the sense of Jeffreys—simplify the law. In fact, simplicity is always a function of the language employed (i.e., the concepts, symbols, or geometry) and hence is not a desirable basis. Jeffreys probably would say to use the simplest language, for later he tells us that "we regard Cartesian co-ordinates as the physically fundamental ones on account of our principle that the fundamental laws of physics are simple in form." Despite this statement, what one regards as the simplest language depends on one's familiarity with the language and what one talks about. Furthermore, do we expect success with simple

laws because of their simplicity? A review of past experiences might indicate the contrary. The acceptance of simple laws is only an acknowledgment of our ignorance.

After concluding that "extrapolation over an indefinitely wide range can be carried out with the full probability of the law" and justifying "the inferences concerning conditions at the centre of the earth or millions of years ago that form so large a part of geophysics and cosmogony," Jeffreys attacks the subject of errors. A rather brief though interesting discussion of the nature of errors is given along with least-square theory, but the literature on this subject is vast and hence no striking contributions can be expected. Though one is surprised to find Jeffreys making the following astounding statement in regard to measurements of lengths or time intervals by the methods of difference, "When a single quantity has to be measured as the nearest multiple of the step, the same observation may be made an infinite number of times without in the least affecting the precision of the adopted value. But when it is determined by difference, and the measure is repeated a large number of times, the standard difference between the adopted and true values may be reduced indefinitely," naturally one examines the assumptions required for this remarkable result. The author again fails explicitly to state all vital assumptions but, inasmuch as he employs inverse probability, he requires the prior probabilities both for the different values of the quantity and for the readings, given the value of the quantity. His assumption of "equal likelihood" for the former is reasonable, but the statement that "the probability of getting the reading n is 1 when" the quantity is between $n\pm\frac{1}{2}$ and otherwise 0 is not derivable from the first assumption and, therefore, must be an additional hypothesis. Furthermore, even a simplicity hypothesis would hardly justify assuming that, if the quantity is $n+.49999$, we shall always read the nth step but, if it is $n+.50001$, we shall with equal certainty read $n+1$. Unfortunately the results are dependent upon the hypothesis employed and with other hypotheses, which seemed at least as reasonable as those of Jeffreys, quite contrary results were obtained.

A chapter is devoted to the nature of physical magnitudes and the distinction between fundamental and derived magnitudes. This is followed by a chapter on mensuration which, according to Jeffreys, "deals essentially with the relations between measurements of distance on rigid bodies." Both of these chapters might be of interest to the mathematician. In the former he criticizes the Whitehead and Russell treatment of irrational numbers, while in the latter he attempts to develop the subject of mensuration in a manner similar to Euclidean geometry, starting with

the cosine law of trigonometry as a result of experimental verification. It would be interesting to read a development of these ideas, in which all undefined terms and unproved propositions were clearly indicated.

As examples of scientific inference, we find Newtonian dynamics and light and relativity. Although the exposition of these subjects is excellent, yet the major contents of these two chapters will be found in other works. Regarding relativity, we are told that "the general theory of relativity is therefore justified as a physical law up to a certain point, and the simplicity postulate entitles us to extend it further if possible."

After convincing the reader of the security of the underlying laws of cosmogony, Jeffreys considers probability in mathematics. Evidently geophysicists would not attempt to prove Fermat's last theorem, for "in view of the efforts that have been made to prove the theorem, we may say that the probability of this proposition is small, though not absolutely zero."

After reading *Scientific Inference* one will have considerable doubt about the nature of the work. Is it a sober, careful, scientific investigation or a work of fiction? Let us postulate that there is a linear order for scientific works, with these last classes as extremes, and place *Scientific Inference* somewhere in between. Ought we not to be a trifle modest in our claims for scientific laws and regard them as merely empirical approximations to our experimental data? Ought we to permit extrapolations without limit? Let us admit we can learn by experience, but let us regard our laws as convenient and powerful methods of organizing these experiences.

WALTER BARTKY

UNIVERSITY OF CHICAGO

Les Observatoires astronomiques et les astronomes. Par P. STROOBANT, directeur; J. DELVOSAL, E. DELPORTE, et F. MOREAU, astronomes; H. L. VANDERLINDEN, astronomie adjoint de l'Observatoire Royal de Belgique. Tournai-Paris: Etablissements Casterman, S.A., 1931. Pp. 314.

This is a second edition of the valuable volume published by M. Stroobant in 1907, giving re'iable information as to the names of the staffs in the different observatories of the world, together with a summary as to the most important astronomical instruments of equipment. A rather complete questionnaire was sent out in advance, calling for the necessary facts, and those responsible for the administration of many observatories have been careful in complying with the request for full information.

The specialties of the different members of the staff are named and

there is a good Index of these names. The items given include the aperture, focal length, and maker of the equipment, and a brief description of the auxiliary apparatus, such as spectroscopes, photometers, etc. The serial publications of the observatories are also named, with the specifications of the last volume or part issued. This volume is published under the auspices of the International Astronomical Union, and Professor Stroobant has had the assistance of J. Delvosal, E. Delporte, and F. Moreau.

We find this volume indispensable in the office of administration of an observatory. There has been much new equipment added to observatories during the past ten years, and it is often of much importance to know the facts concerning which instruments have been made. It is also exceedingly important to find quickly the names of the observers who may have participated in some discovery. We very heartily recommend this volume to astronomers. It is well printed and has evidently been edited with much care.

F.